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U.S. Army
Environmental
Center

Composting of Nitrocellulose Fines - Hazards Analysis

Report No. SFIM-AEC-ET-CR-95083
Contract No. DACA31-91-D-0079
Task Order No. 0007

October 1995

19951115 089

Prepared for:
U.S. Army Environmental Center (USAEC)
SFIM-AEC-ETD
Aberdeen Proving Ground, MD 21010-5401

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
October 1995

3. REPORT TYPE AND DATES COVERED
Final, September 1993 - October 1995

4. TITLE AND SUBTITLE

Composting of Nitrocellulose Fines - Hazards Analysis

5. FUNDING NUMBERS

DACA31-91-D-0079

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

02281-012-007-0050

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Environmental Center
SFIM-AEC-ETD
Aberdeen Proving Ground, MD 21010-5401

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SFIM-AEC-ET-CR-95083

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

12b. DISTRIBUTION CODE

Unlimited

13. ABSTRACT (Maximum 200 words)
The production of nitrocellulose for munitions purposes results in the production of nitrocellulose fines (NC fines). Due to their reactive nature, an assessment of the level of NC fines that could be safely handled during the composting process has been conducted. Compost mixtures were developed based upon characteristics of NC fines and of amendment materials available in the vicinity of Radford Army Ammunition Plan (RAAP), the Army's current NC production facility. Under a separate Task Order, RAAP conducted reactivity testing to establish reactivity levels. NC fines loading rates between approximately 10 and 35% at 30% moisture met the safety requirements from the RAAP hazard analysis. Based upon these positive findings, a conceptual level analysis of the use of composting technology for the treatment of NC fines was conducted. The composting process is anticipated to yield a nonreactive soil amendment suitable for beneficial uses. The loadings indicated by the RAAP hazards analysis to be nonreactive at moisture levels acceptable for composting were used in the conceptual level development and cost analysis. Using a NC fines throughput of 1,790 lb/day (on a wet basis) and a 35% NC fines loading at 30% moisture, the total 20-year project cost, including contingency, is estimated to be $6,460,900. This corresponds to a cost of $1,000/ton of NC fines, or $310/yd^3 of NC fines. It is recommended that a pilot study be conducted to verify maximum loadings and process kinetics as well as optimizing operating parameters.

14. SUBJECT TERMS

Composting, Nitrocellulose, Reactivity

15. NUMBER OF PAGES
84 — Text
87 — Appendices

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Sta Z39-18
Z98-102

usaecto.cnf

10/17/95

COMPOSTING OF
NITROCELLULOSE FINES - HAZARDS ANALYSIS

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U.S. Army Environmental Center
Contract No: DACA31-91-D-0079
Task Order 0007

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Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

October 1995

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The production of nitrocellulose for munitions purposes results in the production of nitrocellulose fines (NC fines). An alternative for the management of NC fines derived from the production of nitrocellulose is biological treatment via composting. Previous pilot testing at Badger Army Ammunition Plant (BAAP) indicated that NC can be degraded via composting. Composting has the potential to eliminate reactivity characteristic of NC fines. It also has the advantage of yielding a beneficial finished compost suitable for use as a soil amendment.

Due to the reactive nature of NC fines, particularly when dry, an assessment of the level of NC fines which could be safely handled during the composting process was needed. To accomplish this, the U.S. Army Environmental Center (USAEC) has conducted testing and evaluation of the reactivity of NC fines compost. Compost mixtures were developed based upon characteristics of NC fines and of amendment materials available in the vicinity of Radford Army Ammunition Plant (RAAP), the Army's current NC production facility. Under separate Task Order, RAAP conducted reactivity testing to establish reactivity levels. NC fines loading rates between approximately 10 and 35% at 30% moisture meet the safety requirements from the RAAP hazard analysis and are within the overall composting parameters included in the BAAP composting study.

Based upon these positive findings, a conceptual level analysis of the use of composting technology for the treatment of NC fines was conducted. The composting process is anticipated to yield a nonreactive soil amendment suitable for beneficial uses. NC fines loading rates and treatment periods were based on previous composting studies[8] and the hazard analysis conducted by RAAP. The loadings indicated by the RAAP hazards analysis to be nonreactive at moisture levels acceptable for composting were used in the conceptual level development and cost analysis. The NC fines production rate to be used as a basis is 1,250 lb/day (dry basis), or 1,790 lb/day (wet basis). This approximates the average NC fines throughput value as recently reported for RAAP.[6] Using a NC fines throughput of 1,790 lb/day (on a wet basis and a 35% NC fines loading at 30% moisture, the total 20 year

project cost, including contingency, is estimated to be \$6,460,900. This corresponds to a cost of \$1,000/ton of NC fines, or \$310/yd^3 of NC fines. It is recommended that a pilot study be conducted to verify maximum loadings and process kinetics as well as optimizing operating parameters.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

The manufacture and handling of explosives and propellants at Army Ammunition Plants (AAP's) and Army Depots (ADs) has resulted in the production of various types of wastes, which require appropriate treatment and management to minimize and control their environmental impact. The U.S. Army Environmental Center (USAEC), formerly the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), has responsibility for evaluating and developing cost-effective treatment technologies to meet the goals of the Army's environmental program.

One propellant waste for which the USAEC is evaluating treatment options is the solids, or fines, derived from the production of nitrocellulose (NC). The actual material to be treated may consist of NC fines as produced during NC manufacture, or, in the case of historical operations NC mixed with soils from lagoons or pits in which excess NC was stored, under management practices that were common and accepted at the time of their use. One technology, which the USAEC has considered for NC fines or NC fines-contaminated soil, is biological treatment via composting.

NC is a highly substituted cellulose fiber, which is synthesized from cellulosic materials such as wood pulp or cotton, and used by the Army as a propellant (alone or in combination with other constituents) in munitions and rocket motors. NC is produced from the cellulosic material by nitration using nitric and sulfuric acids, followed by various additional processing steps[1, 2]. The degree of nitration can be varied by adjusting acid strength and processing conditions. As a result, NC may contain from 11.11% nitrogen (cellulose dinitrate) to a theoretical level of 14.14% nitrogen (cellulose trinitrate), although practically achievable nitrogen levels are on the order of 13.8%[1, 2, 3, 4]. The higher nitrogen forms are primarily used in munitions, while lower nitrogen forms are used in various products in the coatings, film, ink, and adhesives industries[1, 2].

Manufacture of NC results in the production of NC solids (fines), which are difficult to recover during production due to their small size. These NC fines have historically been discharged with process water into lagoons. A portion of the NC fines, which did not settle in the lagoons, could be discharged to receiving streams. While NC fines are not considered toxic by the U.S. Environmental Protection Agency (EPA)[5], water quality criteria for turbidity and solids requires more effective capture of NC fines. The Army is investigating options to maximize both the recovery of NC fines and the recycle of NC fines into useful product[6]. The USAEC is evaluating composting as a method for treating NC fines, which have not or cannot be effectively recovered or recycled into product. Previous testing by the USAEC has shown that composting can treat NC fines in soils[7,8].

Composting is a treatment process in which organic materials are biodegraded by microorganisms, generally at elevated temperatures. The biodegradation process results in the production of (among other things) metabolic heat, which is trapped within the compost matrix and results in so-called "self heating" of the compost pile. As historically used for such high-organic wastes as wastewater treatment plant biosolids, municipal solid wastes (MSW), and agricultural or yard wastes, the following goals may be met by this elevated temperature process:

- Stabilization of organic matter.
- Reduction in the treated waste volume requiring further management.
- Reduction in moisture content (drying).
- Destruction of pathogenic microorganisms.

By contrast, the principal objective of composting of hazardous or chemical wastes is the efficient and rapid removal or destruction of specific regulated waste constituents or properties. Previous research conducted by the USAEC has shown that a variety of nitroaromatic explosives in soils can be treated by composting[9,10,11]. Additional work has shown that treatment of NC in soils is technically achievable[7,8].

Due to the energetic nature of explosives and propellants, which can result in detonation under shock or thermal stimuli, safety criteria and procedures to avoid shock and thermal

stimuli are of critical importance in all materials handling aspects of NC's treatment. Establishing safety criteria includes considering the levels of contamination that can safely be handled in the treatment process. NC is known to be a reactive material, particularly when dry. USAEC's previous testing for NC in soils (as with other soils composting projects) used only relatively low NC concentrations, in terms of potential reactivity. Composting of NC fines may result in handling substantially higher initial NC levels. The overall objectives of this Task Order were in conjunction with a separate USAEC Task Order to Alliant Techsystems, Inc., Radford Army Ammunition Plant (RAAP), to assess the levels of NC fines that can safely be handled in a compost matrix. To meet this goal, there were two principal technical tasks to be accomplished: (1) formulation of potential NC fines compost mixtures, and (2) reactivity testing of the formulated NC fines composts to establish reactivity levels.

Based on the results of the NC-fines reactivity testing, this report both summarizes the feasibility of NC-fines composting at levels that were demonstrated to be nonreactive, and develops recommendations for subsequent pilot testing for NC fines composting.

1.2 LITERATURE SURVEY

1.2.1 Biotransformation of Nitrocellulose

A key issue in the evaluation of biological waste treatment is the degree to which the target components can be either biodegraded to mineral products or biotransformed to environmentally innocuous or acceptable products. In this regard, several sources have concluded that NC is resistant to direct microbial attack, even by cellulolytic organisms[12,13]. According to various reports[14-19], as cited in Wendt and Kaplan[12], substituted celluloses are generally resistant to microbial attack, with the degree of resistance increasing with the degree of substitution. Some forms of microbial transformation of NC, however, may be possible under certain conditions. Kaplan[20] suggests the following general mechanism for the biotransformation of nitrate esters:

$$>C\text{-}O\text{-}NO_2 \xrightarrow{H_2O} >C\text{-}OH + HNO_3$$

Kaplan also reports that NC is not directly metabolized by microorganisms and suggests that other studies, in which growth on NC was reported, may represent cases where the observed growth was: on other contaminants, on unsubstituted cellulose, or due to the effects of secondary metabolites on NC structure(20). Wendt and Kaplan(12) also cite Urbanski's(21) conclusions that microorganisms growing on other substrates may produce metabolic products that adversely affect the stability of NC. Brodman and Devine(22) report that a fungus, *Aspergillis fumigatis*, indirectly utilized nitrogen from NC when supplied with a supplemental carbon source (by a hydrolysis reaction) without attacking the cellulose (carbon) backbone. Recent studies have been conducted using three fungal strains, *Phanaerochaete chrysosporium, Aspergillus fumigatus,* and an unidentified *Actinomycete* strain. The authors concluded that none of these organisms used NC as a source of carbon under the conditions tested(23). This suggests that the carbon backbone was not attacked. The authors noted, however, evidence of hydrolysis of NC by *Aspergillus fumigatis* and the *Actinomycete* isolate, although the data from various studies were not consistent.

Duran, et al.(24) tested the anaerobic degradation of NC, using a serum bottle method, which indirectly assessed biodegradability by measuring biogas production. These screening studies indicated that, although some evidence of toxicity was observed, microorganisms derived from an anaerobic digester could degrade relatively high concentrations of NC (up to 54,000 mg/L) with appropriate acclimation. The presence of co-substrates, including cellulose, appeared to suppress the toxicity of NC. Other anaerobic degradation tests by Hsieh and Tai(25) used acclimated microorganisms, which were derived from anaerobic digester seed, in serum bottle tests. Various enzymation inducing agents were evaluated for their ability to foster NC degradation. The authors concluded that the tested reagents were not effective in inducing NC degradation in the test systems(25).

It might be noted that, while mineralization (i.e., conversion of organic components to carbon dioxide and mineral products) is often the optimal treatment result, it may not be strictly necessary in all cases. Rather, treatment to render the material nonhazardous may be acceptable. Thus a process that transforms NC into nonreactive material may meet the primary treatment requirement.

1.2.2 Previous Composting Tests for Nitrocellulose

USAEC has previously conducted tests of composting of NC in soils, primarily as a potential remedial technology for sites with residual NC in soils from previous manufacturing activities[7,8].

The first USAEC study used both laboratory and pilot scale testing to evaluate whether NC in soils from Badger Army Ammunition Plant (BAAP), in Baraboo, Wisconsin, could be metabolized by composting[7]. Bench scale testing used two types of compost mixtures (hay-horse feed and sewage sludge with pine shavings). Composting trials were conducted in 1 quart glass jars incubated at 60°C to simulate thermophilic composting. Although the ability of the test compost to self heat was not assessed, compost temperatures between 66 and 77°C (above the incubation temperature) were reported. Each jar was aerated and compost conditions were adjusted as necessary within desired ranges. Due to the lack of a definitive analytical method for NC, a colorimetric procedure based on USATHAMA methods was used.

Perhaps more importantly, however, radiolabelled NC (uniformly labelled ^{14}C-NC) was added to soil used in test composts (in addition to the NC contributed by the contaminated soil) in order to assess the fate of NC in the compost[7]. The evolution of $^{14}CO_2$ from radiolabelled substrates is generally taken as evidence of mineralization; alternatively, the ^{14}C tracer may allow analysis of the partitioning of the organic compound within the matrix. Under these test conditions, rapid and extensive biodegradation of NC, measured as $^{14}CO_2$ evolved from the spiked ^{14}C-NC, was reported. Cumulative $^{14}CO_2$ recoveries (as a percentage of the spiked label) ranged from 44-65% among the various compost treatments after 42 days of treatment[7]. These results suggest that, under simulated composting conditions, biodegradation of the cellulose backbone occurred. This may be significant in light of the previously cited research, which concluded that microbial attack of the cellulose backbone was not achieved.

Following the bench-scale testing, pilot compost tests were conducted in 488-gallon insulated, steel tanks designed to promote self heating[7]. Two compost mixtures were evaluated (hay-horse feed and sewage sludge-wood chips). The compost reactors were aerated by blowers. The compost contained approximately 15% (by weight) NC-contaminated soil from BAAP. Analyses for NC employed the previously-noted modified USATHAMA method. Samples were taken at 0, 3, and 4 weeks of composting. No analyses were conducted at less than 3 weeks because preliminary testing had indicated the production of large quantities of interfering substances during the first two weeks of composting. Thermophilic composting conditions were achieved in all trials; the hay-horse feed systems achieved higher temperatures than the sewage sludge compost. A high degree of removal of NC was achieved in all composts, ranging from 93.1 to 99.7%. Comparison of the observed NC removals with those thought to occur through thermal decomposition alone (using literature data on the thermal decomposition of NC) indicated that the observed rate of NC removal in compost greatly exceeded (by up to 100 times) that attributable to thermal breakdown[7].

During preparation for the pilot phase of this project, USAEC conducted limited testing to assess the reactivity of the sediment, using the following Bureau of Mines tests:

- Gap Test
- Deflagration to Detonation Transition (DDT) Test
- Bureau of Explosives Impact Test
- Thermal Stability Test
- Electrostatic Discharge Test
- Autoignition Test
- Detonation Tests

These tests were run on air-dried samples of BAAP sediments with a NC level of 1.03% (dry weight basis). All tests were negative[7].

USAEC subsequently conducted a field-scale demonstration of aerated static pile composting to decontaminate NC-contaminated soils at BAAP. In addition, the potential applicability of composting to destroy NC fines was investigated[8].

The primary objective of the BAAP field-scale demonstration was to evaluate the potential utility of aerated static pile composting as a treatment and remediation technology for NC fines and NC-contaminated soil. Secondary objectives of the study included an evaluation of the efficacy of thermophilic (55°C) versus mesophilic (35°C) composting, the evaluation of maximum soil loading rates, and a comparison of different process control and material handling strategies[8].

Field-scale aerated static pile composting trials were conducted on two reinforced concrete test pads. Each pad had a concrete berm to contain any incidental runoff, which would be collected and recycled to the compost during operation. A corrugated tin roof on wooden supports was used to cover the piles. Each compost pile was equipped with an aeration system consisting of a perforated polyethylene pipe placed in the wood chip base, and connected to an explosion-proof radial blade blower. The process control strategy employed temperature feedback control of the blower operation. Temperature control points were specified to maintain thermophilic (55°C) or mesophilic (35°C) conditions, depending on the specific compost pile.

Compost trials in the BAAP pilot study used various amendment mixtures (combinations of horse feed, mulch, manure, wood chips, and alfalfa) and soil loadings (up to 32.5% by weight). Process monitoring parameters for each pile included temperature, moisture content, and NC concentration during the composting period. As in the previous study[7], analysis for NC employed a modification of the USATHAMA colorimetric method.

Two compost piles were established during each of two consecutive test phases. Temperature was the primary test variable investigated during Phase I of the project. Of the two piles studied during this phase, one (Pile 1) was maintained with a maximum temperature at approximately the mesophilic optimum (35°C), and one (Pile 2) at approximately the thermophilic optimum (55°C). The compost piles in Phase I actively composted for 151 days. The initial concentrations of NC were 908 mg/kg for Pile 1 and 3,039 mg/kg for Pile 2 at time-zero. At the end of the study period, the concentrations of

NC were reduced to 651 mg/kg and 54 mg/kg for Piles 1 and 2, respectively. Mean percent reductions of NC in Piles 1 and 2 were 28% and 98%, respectively[8].

The ability to compost at different soil loading rates was the primary variable distinguishing the two thermophilic compost piles established during Phase II of the BAAP pilot study[8]. Soil loading was increased from 19% (by weight) in the Phase I piles to 22% in Pile 3 and 32.5% in Pile 4. In addition, during both Phase I and II testing, bags of compost containing NC concentrations as high as 80% (by weight) were placed within Piles 1, 2, and 3 to investigate degradation of NC at high concentrations. In these bags, small portions of compost (approximately 400 cm^3) were spiked with pure NC, placed into porous nylon bags and incubated within the compost. These trials provided data indicating whether high NC concentrations were degradable under composting conditions, although they could not establish whether a high NC mixture would compost by itself[8].

Piles 3 and 4 established for the BAAP pilot study actively composted for 112 days. The initial NC concentrations were 7,907 mg/kg in Pile 3 and 13,086 mg/kg in Pile 4. The final concentrations of NC were 30 mg/kg in Pile 3 and 16 mg/kg in Pile 4. These data represent mean percent reductions in NC concentration of 99.6% and 99.9%, respectively. Significant reductions were observed in contaminant levels in the NC-spiked bags, with only the 80% NC concentrations exhibiting little degradation[8].

The results of this field demonstration indicated that composting is a feasible technology for reducing the extractable NC concentration in contaminated soils. In addition, this field demonstration provided evidence that NC can be degraded at a high concentration when incorporated into a compost mixture. The data obtained in the "bag" experiments indicated that NC fines can be degraded if incorporated into a mixture to be composted at a level much higher than the 3,000 to 13,000 mg/kg present in the Phase I and Phase II piles. Destruction of NC was observed within small quantities of compost specially prepared to contain (by weight) approximately 3, 5, 7.6, 10, 15, 30, and 60% NC. This indicates that composting may be possible for the management of NC fines. These small bags, however, were placed in a mixture generally containing less than 1% NC and which composted

effectively. Although it appears that NC can be degraded at concentrations as high as 60% when incubated at composting temperatures, it has not been established that a large quantity (several cubic yards or more) of a mixture containing high NC concentrations will compost effectively in terms of generating and sustaining elevated temperatures. Additional testing of a high NC concentration compost, rather than contaminated soils, would be required to evaluate this option.

1.2.3 Properties of NC Fines

Formulation of compostable mixtures containing NC fines requires information on the composting properties of NC fines wastes. A preliminary data search was conducted to identify pertinent NC fines characteristics. Sources included published literature[1,2,4], and information provided by RAAP[3,26]. These data are summarized in Table 1-1. In interpreting these data, it should be recognized that specific analyses for the actual NC fines material, as received for composting, are generally not available, simply because there has been no previous need for such characterization. The data in Table 1-1 reflect published characteristics of the NC product itself, as well as approximations based upon RAAP records (e.g., the shipping weight for NC products has been used to estimate the bulk density of NC fines sludge). With respect to moisture level and bulk density, it is also recognized that NC fines stored in lagoons or tanks may exhibit very high moisture levels. Dewatering this slurry to minimal moisture levels required by safety criteria, however, would most likely be accomplished before composting.

1.2.4 Effect of Waste Properties on the Composting Process

Composting of soil, regardless of the nature of the contaminant, differs in significant ways from conventional composting due to the high density, low organic content, and dryness of soil. Based on the data in Table 1-1, NC fines also may differ from either soil or conventional composting in some aspects, which may affect the compost recipe and process.

Table 1-1

General Characteristics of Nitrocellulose Fines Waste

Property (units)	Value or Range	Comment
Source	Cellulose (wood pulp or cotton linters), nitrated with HNO_3/H_2SO_4	Various sources, levels of nitration and other particulars depending upon product end use.
Nitrogen Content (as N) in typical RAAP waste	12.4 - 13.05%	Pure products range from 11.11 to 14.14%
Moisture Content, by weight, minimum	25 - 30%	Minimum allowable based upon safety/handling considerations. NC in lagoons is liquid (pumpable). Can be pressed to ±25 to 30% safely.
Bulk Density	22 - 24 lb/ft^3	Based upon verbal report on product shipping data.
Particle Size Distribution	$<100\ \mu$	
Inert (Ash) Content	0.4 - 1.0%	Estimated: Ash content in product typically no more than 0.4%; $NaCO_3$ added during processing at 0.5%
Melting Point	>135°C	
Decomposition Rate in Water at 50°C (% available HNO_3 liberated per hour)	1.11×10^{-5}	
Solubility: Water Alcohol, ethers, esters	 insoluble high, variable	Solubility varies with solvent and type of NC; but water solubility is low.

USAEC's previous work has demonstrated the potential differences between composting explosives-contaminated soils and sediments and more conventional composting operations. In conventional composting of biosolids, MSW, and agricultural/yard wastes, which are inherently rich in organic content, the waste itself provides the substrate for microbial heat production. Even highly contaminated soils, however, contain insufficient organic levels to support self heating of the compost; the relatively inert soil may also act as a heat sink. Consequently, composting contaminated soils is accomplished by mixing organic amendments with the soil to provide a substrate for microbial heat production. Furthermore, it is likely that the added amendments not only provide a diverse source of microbes, but also serve as substrates for co-metabolic transformations.

USAEC's previous testing for composting of NC in soils, which showed that NC could be treated by composting, was similar to other contaminated soil composting using organic amendments[6, 7]. These studies serve as a starting point for the evaluation of NC fines composting, because NC fines differ from NC-contaminated soils in several potentially significant ways.

- NC fines are nearly all organic. (The degree to which this organic content will serve as usable substrate for the composting operation is uncertain).
- The bulk density of NC fines may be considerably less than contaminated soils.
- The nitrogen content of NC fines is substantially higher than nitroaromatic-contaminated soils.

These and other properties of NC fines waste may affect the selection of amendment recipes for effective composting.

1.2.5 Composting Parameters

A variety of environmental and operating parameters affect the performance of a compost system, including the following:

- Types and concentrations of organic constituents.
- Nutrient levels (particularly the carbon to nitrogen (C:N) ratio).
- Moisture content.
- Compost temperature.
- Oxygen level.

Of these parameters, the first three in particular are largely determined by the mixture of materials used in the compost pile (although moisture can also be manipulated during operation). The temperature achieved is a function of the compost mixture chosen, as well as other operating conditions and controls. Oxygen level is likewise a function of the rate of decomposition, the mechanism(s) of air supply, and such physical properties of the compost as bulk density, particle size, porosity, and texture. Therefore, in formulating an amendment mixture for composting materials such as NC or contaminated soils, the types and proportions of amendment ingredients should be selected to provide a starting compost mixture having the desired characteristics. Table 1-2 summarizes general ranges for pertinent composting parameters as well as the target levels used in USAEC's test of windrow composting for explosives-contaminated soils at Umatilla Depot Activity(11,24). Table 1-3 summarizes general conditions for conventional composting(24). These general ranges were used to guide the amendment/mixture formulation process in this project.

As expected, the desired properties may vary significantly among different ingredients. Variations may also be seen in a particular amendment ingredient (i.e., animal waste obtained from different sources) due to differences in the ways they are produced and managed. For example, farming practices may vary for animal or agricultural wastes. The amendment/mixture selection process used in this study were typical amendment characteristics cited in the literature, rather than site-specific formulations for reactivity

Table 1-2

Target Ranges for Initial Compost Mixtures

Parameter	Typical Range for Conventional Composting[a]	Target Level for Explosives in Soil at UMDA[b]
Bulk Density, lb/cy	< 1100	1400
Solids (% wet basis)	NS[c]	70
Moisture Content (% wet basis)	40-65	30
pH	5.5-9	NS
Carbon:Nitrogen (C:N) Ratio	20:1-40:1	31:1
Organic Matter (% wet basis)	NS	17
Total Nitrogen (% wet basis)[d]	NS	0.28

(a) Source: Reference 27
(b) Source: Reference 11
(c) Not specified
(d) Total Kjeldahl Nitrogen

Table 1-3

Conditions for Conventional Composting[a]

Condition	Reasonable Range[b]
Carbon to nitrogen (C:N) ratio	20:1-40:1
Moisture content	40-65%[c]
Oxygen concentrations	> 5%
Particle size (diameter in inches)	1/8 to 1/2
pH	5.5-9.0
Temperature (°C)	45-65

(a) Source: Reference 24

(b) These recommendations are for rapid composting. Conditions outside these ranges can also yield successful results.

(c) Depends on the specific materials, pile size, and/or weather conditions.

testing. While it is reasonable that the mixtures so formulated would effectively compost, no testing was conducted in this test program to confirm this assumption.

1.3 OBJECTIVES

The overall objective of this Task Order is to prepare a report summarizing the results of the hazards analysis, including recommendations for conducting a pilot demonstration study. The hazards analysis examined the various combinations of NC fines and compost amendments to determine the quantity of NC fines that can safely be placed in a compost pile. This was accomplished through testing and analysis to evaluate conditions and levels under which NC fines in typical compost mixtures exhibit reactivity under standardized test procedures.

Two principal technical tasks were required to meet this objective:

- Evaluation and preparation of compost amendment mixtures that may be used for NC fines composting.
- Reactivity testing of selected combinations of NC fines and amendment mixtures to determine reactivity levels.

The information gained during these tasks are summarized in this report and used to formulate a test plan for a pilot demonstration. Section 2 of this report describes the selection process used by WESTON in compost mixture formulation. Section 3 describes the reactivity testing program conducted for USAEC by RAAP. The data presented in these sections are then used in the Conceptual Evaluation of NC Fines Composting Feasibility in Section 4. Finally, the recommended pilot test approach is presented in Section 5.

SECTION 2
COMPOST MIXTURE FORMULATION

2.1 BACKGROUND

To provide test materials to determine the reactivity levels in NC/compost, preliminary compost amendment recipes were formulated. Recipe formulation was conducted by Woods End Research Laboratory, Inc., (WERL) under subcontract to WESTON, using principles developed on previous composting projects. These recipes were based on the general desired properties of compostable mixtures as discussed in Subsection 1.2.5, the known properties of NC waste as identified in Subsection 1.2.3, and the types of potential compost ingredients available in the vicinity of RAAP. It should be noted that these mixtures are based on available data with regards to the NC fines and amendment ingredient properties, and no testing was conducted to confirm the compostability of these mixtures.

During pilot or full-scale composting, amendment ingredients would be obtained and mixed on an "as received" basis, including in particular, natural moisture levels in the various ingredients. However, in order to facilitate the mixing process and to allow reactivity testing at varying total moisture contents to meet the particular needs of this project, it was necessary that all amendment ingredients be as dry as possible for mixing.

Consequently, amendment evaluation and compost mixture formulation was conducted using anticipated "as received" characteristics as discussed in Subsections 2.2 and 2.3. The resulting recipes were converted to the corresponding dry weight for use in this project. Dry weight recipes are presented in Subsection 2.3.

2.2 IDENTIFICATION OF POTENTIAL AMENDMENTS AND SOURCES

Potential compost amendments within the RAAP vicinity were identified and evaluated through the following steps:

1. Potential sources for specific types of compost ingredients that have been used on previous projects were identified through such sources as local advertisements, a computer database search, and discussions with the local offices of the Virginia Agricultural Extension Service and local universities.

2. A telephone survey of candidate suppliers was conducted to discuss type and availability of ingredients.

3. A site visit to selected sources was conducted to further evaluate candidate ingredients. Notes from the site visit are provided in Appendix A.

This effort indicated a ready supply of certain typical compost ingredients from which recommended recipes were developed. As discussed previously, chemical and physical properties may vary even among different sources for particular ingredients. Since no analysis of actual materials was conducted, nor was direct inspection made of particular ingredients beyond those examined on the trip, these recommendations constitute an estimate based on literature information and previous experience. Deviation of actual materials from expected normal traits will influence the final mixtures.

2.3 EVALUATION OF AMENDMENTS

2.3.1 Effects of NC Properties

The properties of the selected ingredients, and the properties of the NC wastes were combined to formulate mixtures approximating those of an acceptable compost as discussed in Subsection 1.2.5.

The computational procedure used in recipe formulation requires some understanding of the contribution of the material (in this case NC) to the composting process. For example, not only the total carbon and nitrogen content of the material, but the availability of these constituents to the microbial population is important. As discussed in Subsection 1.2, the manner in which NC is susceptible to microbial activity is unclear. Since the fate of NC in composting is somewhat uncertain, the extent to which any NC property will be relevant to compost mix formulation is likewise unknown. For computational reasons, the following possible scenarios were considered:

1. NC is inert and makes no contribution to compost properties.
2. NC contributes fully (e.g., C and N) to compost properties.
3. NC contributes water and porosity only to compost properties.

It was assumed for purposes of developing amendment recipes that Scenario 3 above is the most realistic or likely scenario. Therefore, it was assumed that the NC fines contained 30% moisture and has a density of 23 lb/ft^3 (620 lb/yd^3) (see Table 1-1). As it turns out, it appears that these NC factors are not critical to the outcome of the mix, because of the contributions of other ingredients. For example, manure contains more water and straw contains more porosity than NC fines. Therefore, the contribution from these materials bracket the properties of NC fines. As will be discussed in Subsection 2.3.2, two mixtures were formulated using manure/straw components.

If, however, Scenario 2 above is assumed, the mixture computation indicates that no added nitrogenous matter is needed. Furthermore, the porosity of the compost resulting from Scenario 2 would be very high (low bulk density) since only carbonaceous matter is required from the amendment. This scenario would typically be avoided, but it may be worthwhile for later examination as it is likely to maximize the potential for NC degradation. For purposes of these recommendations, a special recipe for Scenario 2 was identified as the third basic mixture.

2.3.2 Compost Ingredients

Compost ingredients were chosen with the following general considerations:

- Availability of relatively large amounts in the vicinity of RAAP.
- Appropriate physical and chemical characteristics.
- Lack of negative properties (odor, residues, etc.) that could adversely affect the outcome of composting.

The source ingredient survey information confirmed the local availability of animal manures, including dairy and horse manure, the two prime candidates for compost blends. Additionally, the survey confirmed the availability of straw and sawdust. Therefore, the following initial recipes were developed:

Mixture 1: A base of dairy manure plus straw, with an estimated C:N ratio of 30:1 and moisture of approximately 35%.

Mixture 2: A base of horse manure/bedding and added straw with an estimated C:N ratio of 50:1 and moisture of approximately 55%.

Mixture 3: A base of sawdust and straw with a small fraction of manure to provide a source of microbial seed; estimated C:N ratio of 70:1 and moisture of approximately 40%.

Dairy manure was chosen because it is a reliable substrate for composting. A database of approximately 50 previous analyses of dairy manure was examined in order to construct a typical profile. Dairy manure has good general traits and medium-high bulk density, which for the low-density NC would appear to be an important consideration. It typically exhibits a relatively coarse texture and a low C:N value. Furthermore, dairy manure requires only the addition of straw to be fully amenable to a mixture of NC at any loading rate. A mixture of dairy manure and straw was selected as Mix 1 (Table 2-1).

Horse manure/bedding was additionally selected for its properties of coarse texture and a medium-high C:N ratio. A database of approximately 20 previous analyses of horse litter was consulted to construct a typical profile. Horse litter is easily mixed and handled; it is available throughout the region and it may be the most ideal ingredient for ease of handling and positive NC decomposition. A mixture of horse manure and straw was selected as Mix 2 (Table 2-1). Horse manure is considered to be a blend of manure and bedding (shavings and straw). It is customary to bed horses with a mixture of clean straw and pine shavings. Therefore, a blend consisting of horse manure/shavings and clean straw was selected.

Straw and sawdust were selected as supplemental bulking and/or drying materials. These ingredients have C:N ratios that are classified as moderately high (straw) to very high (sawdust). Since different types of both straw and sawdust are available, the recipes may

Table 2-1

Proposed Basic Compost Blends for RAAP Nitrocellulose Composting

Mixture ID	Main (M) Ingredient	Supplement (S) Ingredient	% Inclusion M:S w/w[1]	Estimated Volumetric Ratio M:S[2]
Mixture 1	Dairy Manure	Straw	75 : 25	1 : 1.2
Mixture 2	Horse Manure	Straw	56 : 43	1 : 1.5
Mixture 3	Sawdust	Straw/Dairy Manure	75 : 20 : 5	4 : 1 : 0.25

[1] Wet weight/weight basis, as is typical of fresh, untreated ingredients.

[2] In typical, fresh condition.

have to be adjusted at the time of mixing, based on actual materials available at that time. It is assumed that straw will be obtained in bales and sawdust in loose form. A mixture of these two ingredients served as a low nutrient compost base for NC (Mix 3, Table 2-1). A small quantity of manure was included in Mixture 3 to provide additional microbial seed.

Another common material used in composting processes is chicken litter. The survey results do not indicate a plentiful supply. Additionally, chicken litter may impose other constraints. One is the potential for odor and the other is its high nitrogen content. If Scenario 2 as previously described proves to be true, the nitrogen would not be needed due to the high nitrogen content of NC (assuming it is available to the microbial population).

2.3.3 NC Addition Rates

The mixture recipes discussed in Subsection 2.3.2 would provide basic compost blends into which NC would be added at variable rates. The influence of NC on the C:N ratio in the starting compost mixture was evaluated on a preliminary basis to understand the potential limitation of raising the nitrogen content too high. The potential release of nitrogen from NC, which is uncertain, can act positively to drive compost degradation by providing the primary nutrient source; however, too much nitrogen would drive the pH up, cause large amounts of ammonia to be released, and possibly result in noxious compost.

Table 2-2 evaluates the potential influence of initial NC loading on the starting C:N ratio for each of the three base compost blends. These data suggest that NC composition in the starting compost should not exceed 39% by weight in order to maintain the C:N ratio at or above 10:1 (assuming all NC is utilized). Reactivity testing of higher ratios, however, is warranted because the availability of nitrogen from NC is not certain. If, in fact, the NC does contribute N as described in Scenario 2, and the C:N ratio falls below 10:1 as a result of nitrogen release during composting, the potential effects noted above must be addressed. Other factors such as bulk density and moisture may also play a role in limiting NC addition.

Table 2-2

Potential Influence of the Rate of Nitrocellulose Addition on Apparent C:N in Composts

C:N Ratio	Compost Recipe		
	Mixture #1	Mixture #2	Mixture #3
	......NC % w/w (as is).....		
8	25	57	50
10	17	39	37
15	9	23	22
20	4	13	15
25	2	9	12
30	0	6	9
40	---	2	6
50	---	0	2

See Table 2-1 for mixture ingredients.

Since it is assumed that NC is not available as a compostable substrate, the use of the C:N ratio as a limiting factor is uncertain and results in conservative guidelines. NC content could be increased if the nitrogen release is expected to be significantly less than 100%. The data in Table 2-2 indicate that the proposed compost recipes provide sufficient latitude to tolerate large amounts of NC fines regardless of nitrogen release rates.

2.3.4 Other Considerations

Although the compost mixture is determined largely by the C:N ratio, other properties must also be considered for effective composting. These properties include mixture pH, moisture content, and carbon content. The pH of the NC fines will influence the mixture pH. The addition of $NaCO_3$ during processing may raise pH to a point that would require consideration.

Moisture content also warrants consideration. Of particular concern is the initial water content after mixing and the loss of moisture during composting. With regard to the initial water content of the compost mixture, it has been assumed that the specified ingredients contain a minimum of 35% moisture. The optimal moisture level for composting is defined as percent saturation. Some desired ranges for moisture contents for each of the test mixtures, based on their anticipated water holding capacity, are presented in Table 2-3. The moisture content is determined by the properties of the ingredients themselves and must be determined at the time of mixing. Loss of moisture during composting cannot be predicted from these compost mixture projections. If, for example, the sawdust is dry (50% moisture was assumed) water would be added prior to mixing.

Another concern is the varying content of wood shavings in horse litter. If the percentage varies greatly from that which was assumed, then the supplemental material, as defined in Table 2-1, may have to be limited on the basis of the carbon content. These contingencies are best dealt with during the mixing process.

Table 2-3

Recommended Moisture Ranges for Composting Based On Proposed Compost Amendment Mixtures

Mixture	Estimated Water Holding Capacity (% by weight as is[a])	Recommended Moisture level (% by weight as is [a])		
		Low	Ideal	High
1	80	35	64	75
2	70	30	57	65
3	75	32	60	70

[a] % by weight as is (moist basis).

As previously discussed, NC blending into compost differs from other forms of explosive/propellant composting for many reasons. A significant factor is the uncertainty of the contribution of carbon and nitrogen contained in the NC. If there is no NC breakdown during composting, then there is no contribution of nitrogen to the process. The compost recipes defined above take this into account. If there is NC breakdown in the compost system, which is hypothesized based on previous composting test data, its contribution to the composting process may be significant. It is anticipated that the projected recipes adequately allow for a contribution from NC, but it cannot at present be ruled out that this contribution alone will act to restrain the NC addition rate, because of the high nitrogen content of NC.

Another difference between NC fines composting and composting of contaminated soils is the low bulk density of the NC, in contrast with previous testing(10) wherein the contaminant was bound to dense soil residues. The bulk density of NC fines is moderately low, but greater than straw. Thus any amount of NC, theoretically, can be added to compost without the markedly negative effect on compost bulk density found for contaminated soils. On the other hand, a high loading rate of NC, combined with a loose-textured amendment matter during composting, will produce a porous compost that may tend to dry out rapidly, increasing the potential hazard. An optimal rate of NC addition based on bulk density and C:N ratio can be adequately determined through bench-scale or pilot testing.

2.4 DRY COMPOST RECIPE FORMULATION

2.4.1 Background

In order to meet the specific requirements of the reactivity testing program, it was determined that all recipe projections and mixing operations should be on a dry weight basis, and that ingredients supplied to RAAP should be predried to the extent possible. In order to meet this new requirement, ingredients were obtained and dried through a commercial fertilizer producer. Compost recipes were recalculated based on the characteristics of the dried ingredients. Subsection 2.4.2 discusses the ingredient procurement and drying effort. Subsection 2.4.3 provides dry mixture recipes.

2.4.2 Ingredient Preparation

Compost ingredients were obtained and prepared for the RAAP reactivity testing program through a commercial producer of fertilizer and compost products in Gap, Pennsylvania. The goals of the preparation steps were to dry the ingredients and to reduce their particle size to provide suitable mixing characteristics.

The raw ingredients were obtained from farms in the vicinity of Gap, Pennsylvania, where ingredient preparation was to take place. These local materials (dairy manure, horse manure, straw, and sawdust) were judged to be generally comparable in overall physical characteristics to those that would be available in the Radford, Virginia area.

Manure materials were prepared by two stage drying followed by pulverization with a hammer mill (using a 1/2 inch screen). The first drying step took place in a commercial fuel-oil-fired rotary drum dryer with a residence time of 20 minutes. This step removed approximately two-thirds of the moisture typically present in fertilizer production. In the second drying stage, warm air was blown under a bed of the product for approximately 48 hours to achieve additional drying. The straw and sawdust materials, which were received relatively dry, were simply pulverized in the hammer mill.

Following preparation, the ingredients were separately packaged in plastic-lined plastic mesh bags of approximately 3 ft^3 and shipped directly to RAAP.

2.4.3 Dry Compost Recipes

Based on the observed and estimated characteristics of the prepared compost ingredients, the compost mixture recipes provided in Table 2-1 were converted to a dry weight basis for use in the RAAP reactivity testing program. These dry mixture recipes, used in preparing NC/compost mixtures for reactivity testing, are provided in Table 2-4.

Table 2-4

Dry Weight Mixing Ratios for Nitrocellulose Compost Reactivity Testing

Mixture	Main Ingredient (M)	Supplemental Ingredient (S)	% Inclusion M:S, w,w/[a] as delivered[a,b]
1	Diary Manure	Straw	50 : 50
2	Horse Manure/Bedding	Straw	45 : 55
3	Sawdust	Straw/Dairy Manure	65 : 33 : 2

[a] As delivered (dried and milled).

[b] Estimated at 17% moisture in manure samples as delivered.

It should be noted that these dry weight recipes were prepared solely to allow effective mixing for purposes of the reactivity testing program, and to allow moisture content to be used as an experimental variable where appropriate. Field tests and full-scale composting would be based on the recipe criteria specified in Table 2-1 and would use as-received (moist) ingredients, with projected final desired moisture levels in the initial mixture as indicated in Table 2-3.

SECTION 3
REACTIVITY TESTING RESULTS

3.1 GENERAL

RAAP performed reactivity testing on NC fines compost mixtures for USAEC, as outlined in the Combined Test Plan(28). The final report from the testing program is provided as Appendix B. As summarized in that report, testing was conducted using NC alone and in combination with three compost mixtures at various moisture levels. Reactivity to flame and shock stimuli were evaluated using standard test procedures to determine maximum NC levels and minimum moisture levels to control reactivity. Additional testing for sensitivity to impact, friction, and electrostatic discharge was conducted on selected formulations for use in evaluation of potential risks during actual composting operations.

3.2 TEST RESULTS

Figure 3-1 summarizes those findings of the RAAP Final Report, which most directly affect the formulation of the compost mixture. The study concluded that NC compost mixtures exhibited similar reactivity under flame and shock stimuli at moisture levels up to 25%. Above this moisture level, NC compost required more moisture to avoid flame reactivity than shock reactivity. In other words, at a given moisture level, NC compost was more sensitive to flame stimulus than shock. NC alone (no compost) required 55% moisture to be nonreactive in the DDT Test.

The reactivity testing program results also indicated that dry NC compost mixtures did not react under the DDT Test at less than 12% NC. Dry NC compost mixtures containing less than 10% did not propagate an induced explosive reaction in a ≤ 2.5-inch diameter, schedule 40 steel pipe in the critical diameter for explosive shock propagation test.

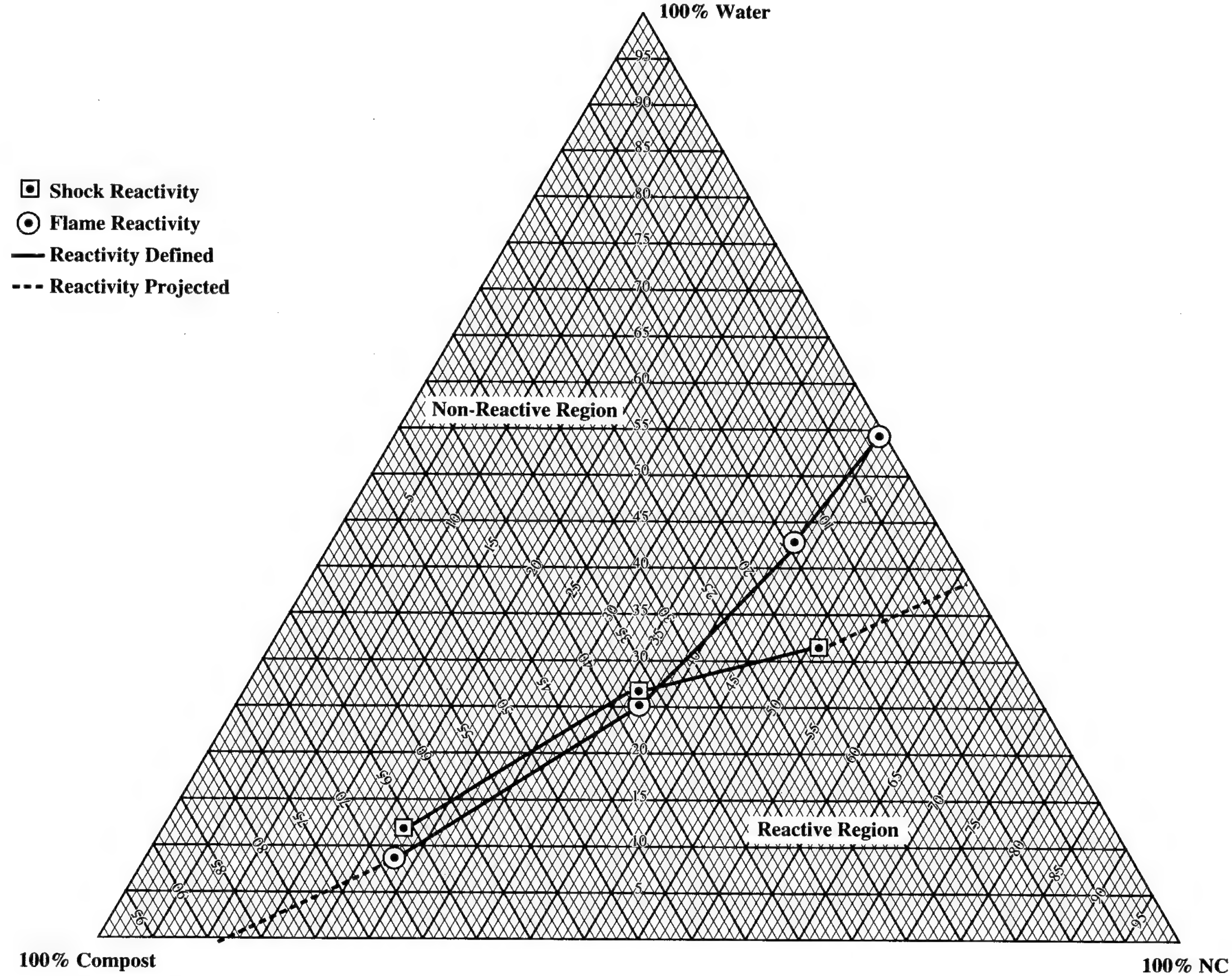

FIGURE 3-1 NC/COMPOST MIXTURES REACTIVITY SUMMARY

3.3 RELATIONSHIP OF TEST RESULTS TO COMPOSTING

As suggested above, the non-reactive region on Figure 3-1 appears to establish NC and moisture levels that can be accommodated in composting from the standpoint of reactivity. Assuming that the NC level relative to the compost mass declines during the compost process, and that moisture content can be maintained by water addition to offset the drying effect of composting, the criteria established by these data would apply most strictly to the initial (startup) condition. After startup, the level of NC relative to moisture content should decline. Assuming, for example, initial conditions of 35% NC and 35% moisture, degradation of NC with external control of moisture will cause the compost characteristic to move further into the non-reactive region, as suggested in Figure 3-2.

Consequently, the NC and moisture criteria defined by Figure 3-1, in conjunction with other potential constraints on these parameters discussed in Sections 1 and 2, will be used to establish the "design basis" for NC fines composting (Subsection 4.2).

In addition, it is proposed that the presumed treatment standard for NC fines composting to mitigate the reactivity characteristic, be 10% NC fines in compost, the level below which reactivity under the conditions of this testing program would not be encountered regardless of moisture content.

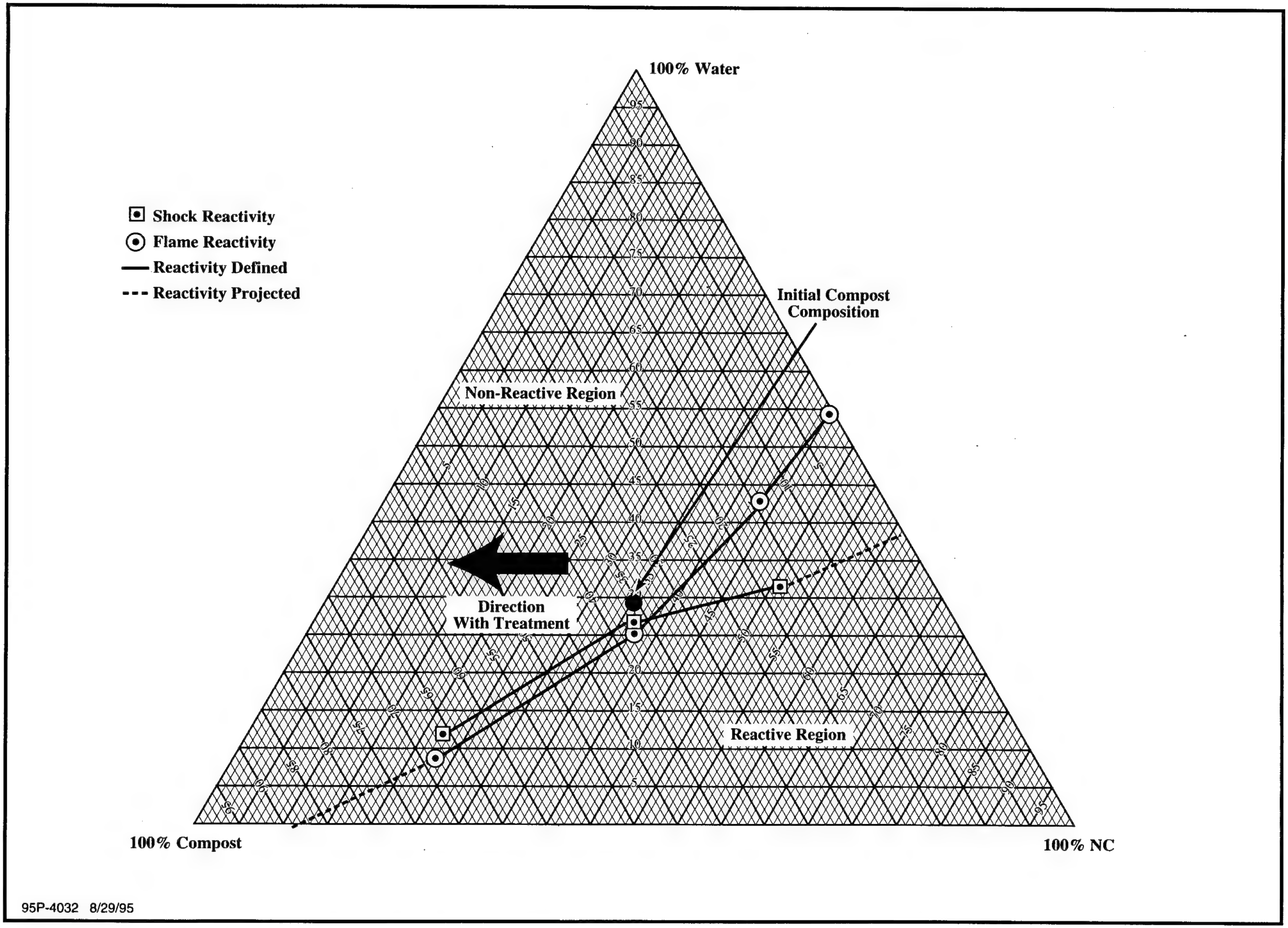

FIGURE 3-2 NC/COMPOST INITIAL COMPOSITION AND PROJECTED CONCENTRATION CHANGES DURING COMPOSTING PROCESS

SECTION 4
CONCEPTUAL EVALUATION OF NC FINES COMPOSTING FEASIBILITY

4.1 BACKGROUND

This section provides a preliminary evaluation of both the NC fines composting facility requirements and costs based on previously identified constraints. This preliminary evaluation can be used to assess the technical feasibility of NC fines composting as a management method. This evaluation will also be used to help define process parameters and variables which warrant attention in future process development testing.

Previous studies[29] have demonstrated the sensitivity of composting economics to the mass of contaminated material (i.e., soil) in the pile. This sensitivity results in large part from the fact that the composting facility size, as well as its capital and operating costs, are sensitive largely to the total volume of material (compost) to be processed, rather than the soil quantity per se. Therefore, the higher the soil (or other source material) quantity relative to compost, the lower the unit cost for treatment of the soil quantity. This conceptual evaluation will consider composting at the maximum NC fines levels in the initial compost considered to be acceptable under the constraints identified in previous sections.

In addition, this evaluation will incorporate the following key process assumptions:

- Windrow composting will be used. Previous testing has shown that windrow operations can be successful for explosives (TNT, RDX) in soils[11] and economic analyses indicate that windrow composting may be more cost-effective than aerated static pile or mechanically agitated methods under comparable operating conditions[29].

- NC fines will be treated to destroy their reactivity characteristic. For this analysis, the nonreactive level will conservatively be assumed to be less than 10% NC by weight in the final product (Figure 3-1). Since NC is not considered toxic[5] it is assumed that toxicity (or other) numerical risk-based cleanup criteria will not apply.

- For this analysis, it is assumed that finished NC-compost will be disposed of at no cost on site. Further work under subsequent assignments will consider the logistical feasibility of NC fines/compost disposal.

4.2 DESIGN BASIS

As discussed in previous sections, a critical factor regarding the compost operation is the level of NC in the initial composting mixture. Based on moisture content, reactivity, and possible available nitrogen content (Table 1-1), the most conservative criterion for the initial compost mixture is 35% NC by weight, provided that both the NC fines and the compost are kept sufficiently moist prior to and during mixing (such that the moisture content immediately upon constructing the pile is no less than 30%). Assuming that both the NC fines and the previously-mixed compost recipe are maintained above 30% moisture at all times, this criterion should be met. As indicated by RAAP, NC fines are maintained above 25 to 30% moisture for safety reasons during all handling operations (Table 1-1).

The second important factor for the conceptual design of the composting facility is the projection of the time required to achieve specified treatment criteria. As discussed in Subsection 3.2, reactivity test data suggest that treatment of NC compost mixtures to less than 12% NC by weight would render the material nonreactive under all moisture conditions. While the overall goal of NC fines composting is to produce a usable soil/agricultural amendment, a worst case assumption would involve the disposal of the product as a waste. In order to be conservative, it is assumed for this analysis that treatment to less than 10% NC by weight would preclude the product from being classified a RCRA characteristic (Reactivity, D003) waste.

Reduction in compost NC levels from 35% to 10% requires a 71% conversion efficiency. The time required to achieve this removal is determined by the kinetics of the biotransformation process.

Data on the rate of transformation achievable in NC composting, particularly at high concentrations, are limited. Table 4-1 summarizes extractable NC data from the final two

Table 4-1

BAAP Pilot Study Extractable Nitrocellulose with Time

Measured NC Content (mg/kg)							
Time	Pile 3	Pile 4	Bagged Compost at Theoretical NC Levels				
(days)	22% NC-Soil	32.5% NC-Soil	5%	15%	30%	60%	80%
0	7,907	13,086	14,309	65,507	114,527	218,627	164,436
29	387	289	15,784	36,033	73,611	219,712	158,724
49	870	996	1,430	21,000	5,199	144,297	-
101	30	16	1,662	-	2,455	68,811	203,003

aerated static pile tests (Piles 3 and 4) from the BAAP study[8]. These final piles were established to evaluate NC removal at higher initial NC levels and higher soil loadings than used in preliminary experiments. Also summarized in Table 4-1 are data from the NC-spiked composts incubated within piles 3 and 4. These data, including standard deviations, are presented graphically in Figures 4-1 and 4-2.

Table 4-2 summarizes first order removal rates derived from the extractable NC data in Table 4-1. Estimated first order removal rates ranged from negligible ($+0.0023d^{-1}$) at very high NC loadings to approximately $-0.06d^{-1}$. Table 4-2 also shows the time required to achieve 71% conversion at each estimated rate. Using these estimates to predict treatment time is complicated by the following factors:

- These data were drawn from an initial pilot test using the aerated static pile method[8]. Subsequent testing for nitroaromatics and nitramine explosives has indicated that better performance can be achieved using agitated (mechanical or windrow) systems.

- These early pilot tests used relatively unrefined amendment mixtures and process controls. Subsequent testing for nitroaromatics and nitramines has indicated that performance improvements can be achieved by optimizing the compost recipe and operating strategy.

- The available kinetic data in Table 4-1 do not fully address the range of NC concentrations that appear to be acceptable based on reactivity testing. Maximum NC levels based on soil inclusion rates were approximately 1.3%. Bagged composts were intended to include up to 80% NC, but, based on initial analytical data, the maximum extractable NC level was approximately 22%.

- The potential effect of high NC levels on microbial activity levels in compost is unknown. Cellulosic materials are, of course, frequently included in compost systems. Furthermore, the toxicity of NC appears to be low. The data in Table 4-1 indicate negligible degradation at measured NC levels of 16%; however, 69% removal was achieved in 101 days at a measured NC level of 22%. This pattern would not normally be expected in the case of concentration-based inhibition.

- Although NC concentrations appear to increase during composting for some instances shown on Table 4-1, the samples are for the most part within the standard deviation bars shown in Figures 4-1 and 4-2. Data anomalies are

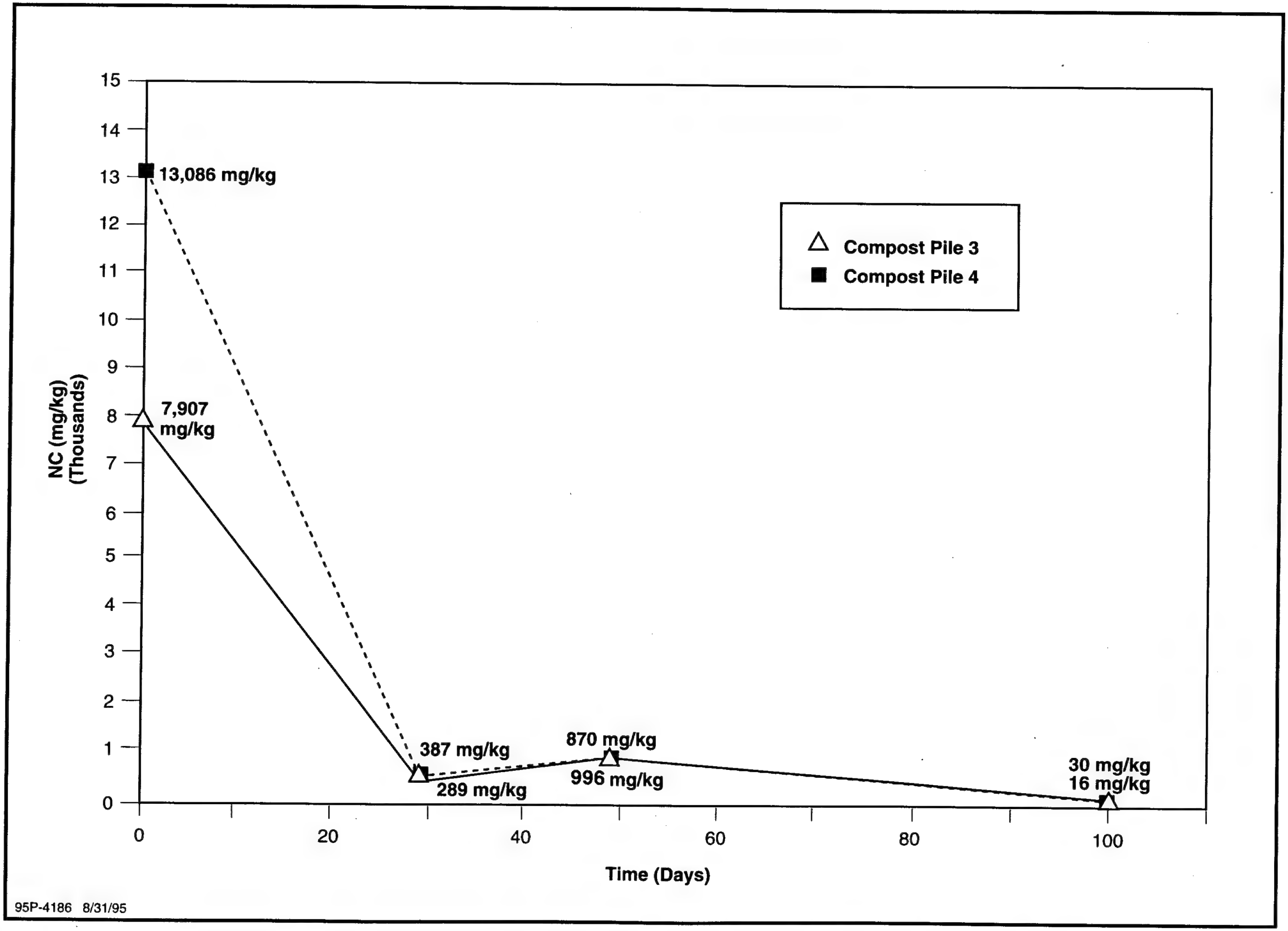

FIGURE 4-1 CONCENTRATION OF NITROCELLULOSE IN BAAP COMPOST PILES 3 AND 4

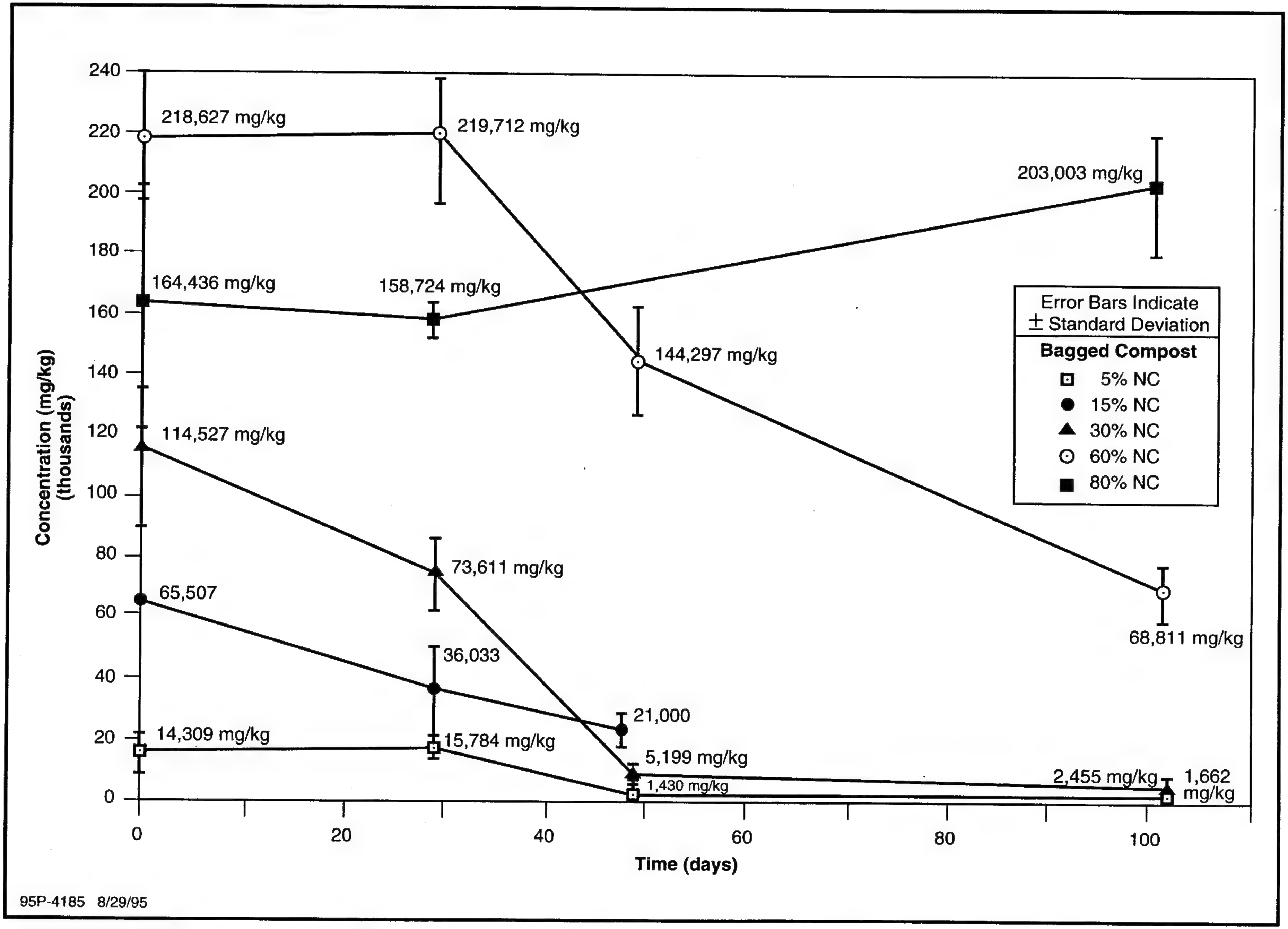

FIGURE 4-2 CONCENTRATION OF NITROCELLULOSE IN BAAP SPIKED COMPOST BAGS, PILE 3

Table 4-2

BAAP Pilot Test Data
Kinetic Estimates and Treatment Periods

Test	Pile 3	Pile 4	Bagged Compost at Theoretical NC Levels				
	19% NC-Soil	32.5% NC-Soil	5%[a]	15%[a]	30%[a]	60%[a]	80%[a]
$k(d^{-1})$	-0.0507	-0.0604	-0.0244	-0.0230	-0.0409	-0.0123	0.0023
r	-0.9372	-0.9227	-0.7878	-0.9971	-0.9129	-0.9587	0.9148
Treatment Period (days), 71% removal	24	20	50	54	30	100	N/A[b]

[a] Weight percentage.
[b] Negligible degradation observed.

probably due primarily to the compost heterogeneity and analytical method error. Milling procedures developed under the USAEC contract since the time of the BAAP study allow for analysis of a much more homogeneous product. However, NC analytical methods have not been improved. Alternative NC analysis methods may be developed during subsequent projects.

In light of these unknowns, a treatment period of 30 days to achieve 71% removal at 35% NC has been selected for this evaluation. This requires a net degradation rate of $-0.0409d^{-1}$. Improved kinetic data obtained during the pilot study will allow for a better approximation of the NC fines treatment period.

4.3 CONCEPTUAL PROCESS DESCRIPTION

For this evaluation, it is assumed that NC fines will be composted on site, using the windrow composting method. As with other types of explosives/propellant composting[29], the basic process (illustrated schematically in Figure 4-3) consists of the following materials handling steps:

1. NC fines receipt and staging.
2. Amendment materials receipt and preparation.
3. Windrow construction.
4. Windrow operation.
5. Windrow removal and disposition of treated compost.

Three trapezoidal windrows (8 ft wide x 80 ft long) will be processed at a time. Ten processing cycles per year will occur.

The following subsections provide a description of the major equipment and the various handling steps in the conceptual compost system based on the process flow and materials balance information provided in Figure 4-3 and Table 4-3. In the following description, equipment sizes and capacities are consistent with these requirements. References to specific equipment by manufacturer or model number are used for illustrative purposes only, and do not exclude the use of other similar equipment.

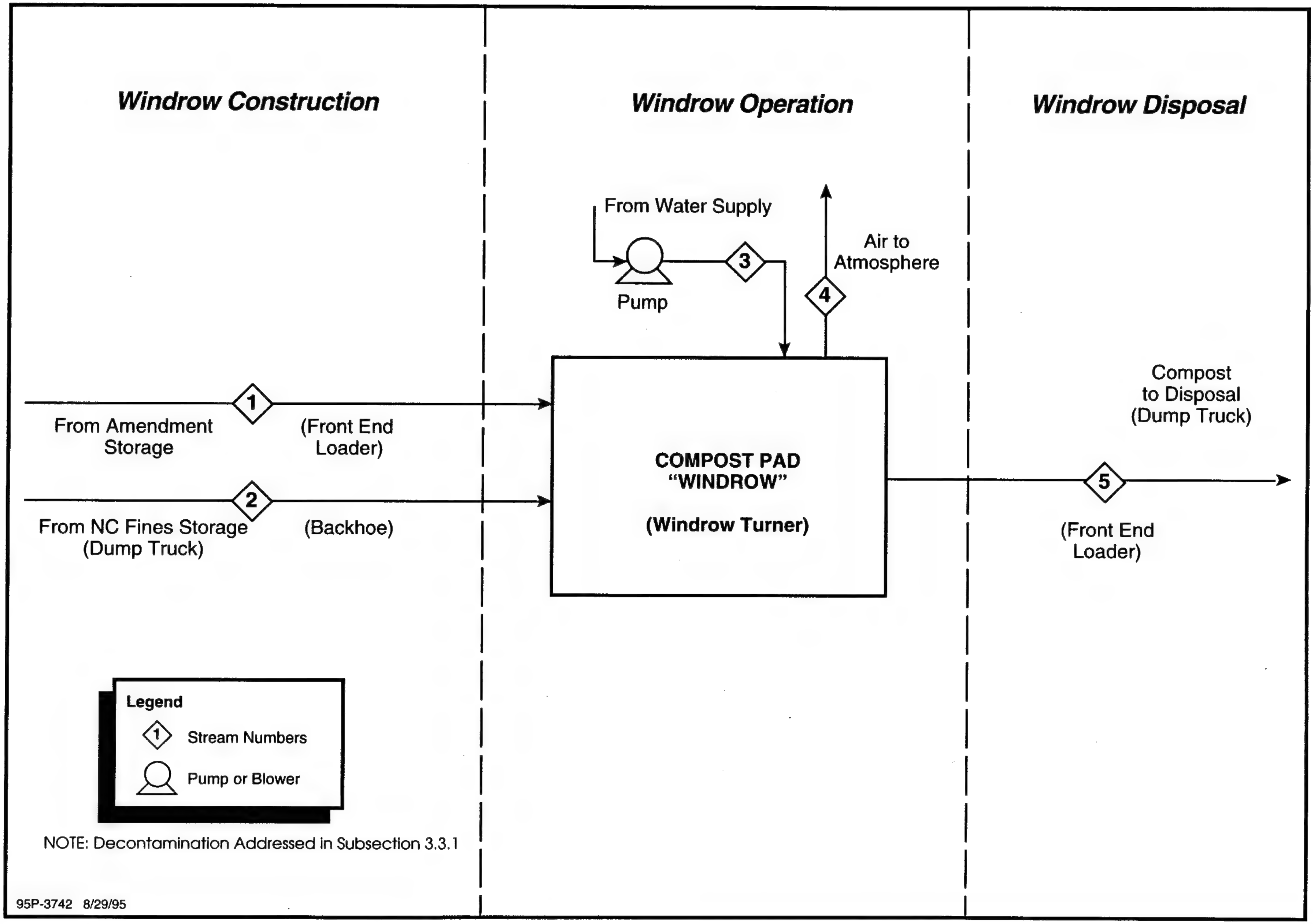

FIGURE 4-3 PROCESS FLOW DIAGRAM FOR WINDROW NITROCELLULOSE COMPOSTING SYSTEM

Table 4-3

Mass Balance for Windrow Materials Stream[a]

Stream Component	Units	1	2	3	4	5
Mass Flow[b]	pounds/cycle[c]	60,800	65,200	4,400	u[e]	u[e]
Volume Flow[b]	yd^3/cycle[c]	150	100	3	u[e]	u[e]

[a] Refers to Figure 4-3.
[b] Wet basis.
[c] 30 days/composting cycle; 10 composting cycles/year.
[d] Refers to water added only. Does not account for water present in NC fines and amendments.
[e] Undetermined.

Note: Assumed densities

- NC fines - 620 lb/yd^3
- Amendments - 420 lb/yd^3
- Compost - 490 lb/yd^3

4.3.1 Receipt and Staging of NC Fines

Moist NC fines would be received periodically at the appropriate time for construction of new windrows. It is essential that NC fines be kept wet (25 to 30% moisture) at all times to prevent ignition. Long term storage at the compost site would be difficult from the standpoint of containment and moisture control. It is expected that the NC fines would remain in the settling pits or storage tanks until needed for construction of the windrow. At the time of windrow construction, only the necessary quantity of NC would be removed from the pit and allowed to drain. While NC must remain wet, transportation and handling of liquid in excess of that required to prevent reactivity should be avoided. The most convenient method of dewatering would be to allow liquid to drain back into the pit from which NC was excavated. The NC could then be transported to the composting area.

4.3.2 Amendment Receipt and Preparation

The amendment delivery and staging area would be located adjacent to, but outside of the composting area and, thus, would be isolated from contact with the NC. The staged amendment materials would be covered with plastic sheeting when windrows are not being constructed. A front-end loader would be used to move the amendments into the composting area. The front-end loader would empty the amendments onto the edge of the pad without driving onto the pad. A front-end loader inside the contaminated area would move the amendments from the pad edge to the windrow. For this preliminary evaluation, 9 tons of amendments (on a wet basis) would be required for each windrow, with 11 tons of drained NC fines material (on a wet basis).

4.3.3 Windrow Formation

Methods for initially forming the windrows (i.e., mixing the bulk NC with amendment materials) have not been tested. The field demonstration for explosives-contaminated soils, however, suggests that the individual ingredients can simply be piled in layers along the axis of the windrow and mixed directly with the windrow turner[11]. It is assumed that this

method would also be used for NC-compost formation. A typical windrow cross-section and windrow turner are shown in Figure 4-4.

It is important, however, to more fully evaluate windrow construction prior to pilot testing. The windrow construction strategy developed in the UMDA pilot test[11] involved soils which, even prior to mixing, exhibited levels of secondary explosives considered to be nonreactive. A case-specific hazard analysis of the mixing equipment was conducted. In the case of NC fines, a determination must be made regarding the ability to initially mix the bulk NC into the pile with conventional composting equipment. While the initial assumption has been made that the NC must be maintained above 25 to 30% moisture at all times during operation, Figure 3-1 indicates that pure NC was nonreactive under the defined test conditions only above approximately 50% moisture. If this more stringent criterion is considered to be applicable under the scenario of mixing the NC into the pile (i.e., if the energy imparted by mixing equipment is considered to be represented by these reactivity tests) it may be necessary for the bulk NC from the storage pits or tanks to be drained only to 50% moisture for incorporation into the pile. It should also be noted that, if it is assumed that the shock sensitivity criterion (rather than the flame sensitivity criterion) is considered to be a more appropriate representation of the windrow turning equipment, bulk NC may be considered acceptably safe at approximately 40% moisture content. (See Figure 3-1).

In order to address these issues, it is likely that a Hazard Safety Analysis will be required specifically addressing the design and operating characteristics of proposed mixing equipment in conjunction with the reactivity characteristics of NC fines. This Hazard Safety Analysis should be conducted as an initial task in the NC fines composting pilot study.

4.3.4 Windrow Operation

4.3.4.1 Windrow Turning

To provide thorough compost homogenization and ensure contact between microorganisms and contaminants, the compost will be turned daily. During turning, oxygen will be

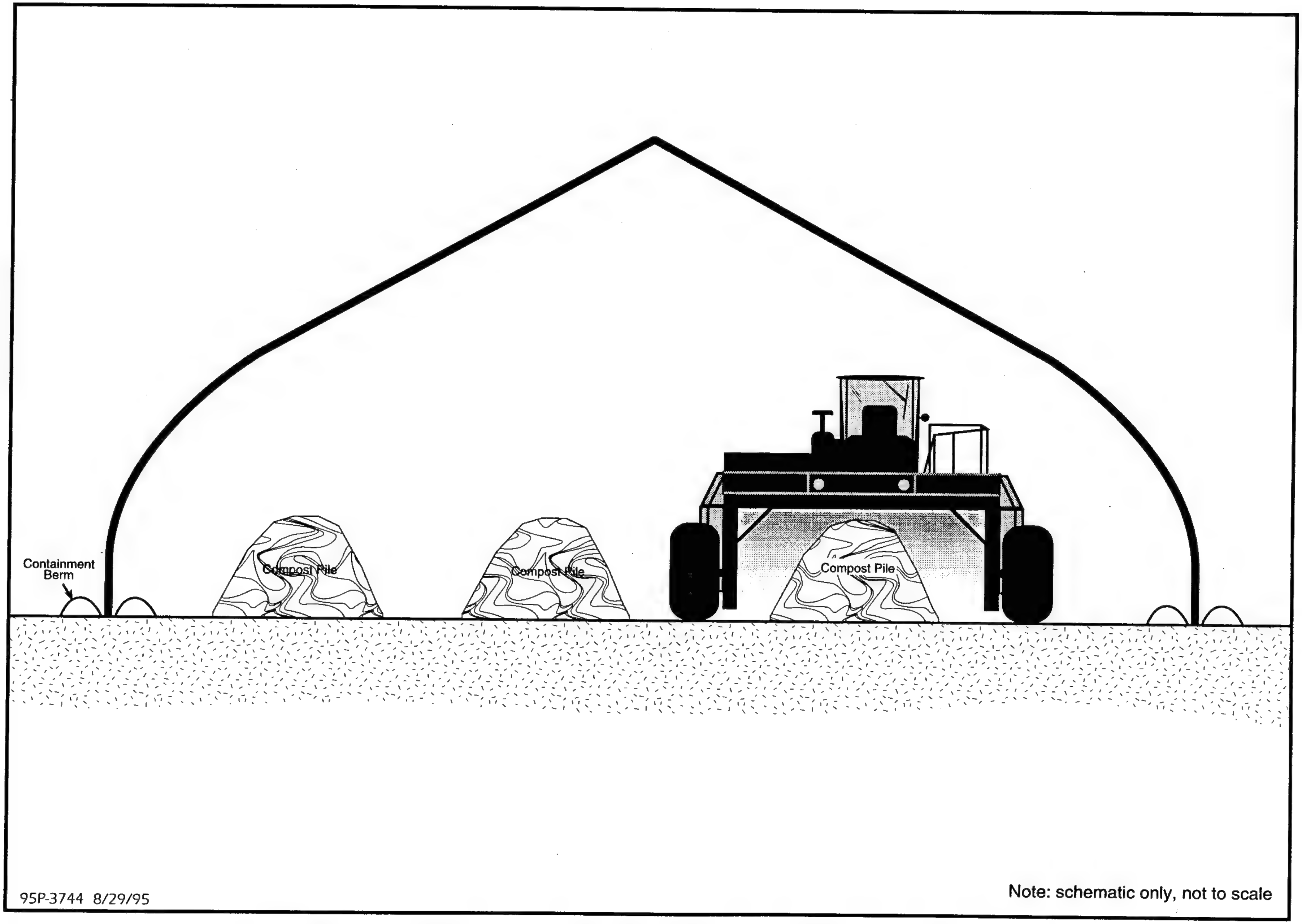

FIGURE 4-4 CROSS-SECTIONAL SCHEMATIC OF WINDROW COMPOSTING

introduced into the windrow and some heat removed from the compost. This is accomplished using the windrow turner. The Sandberger Model SP-100, or equivalent, is recommended because it is small, lightweight, and inexpensive relative to windrow turners used in past composting studies(11). It has a capacity sufficient for the volume of material to be processed in this application. A Hazards Safety Analysis will be needed for the windrow turner prior to its use. One pass through each windrow would be needed. The windrow edges may be reformed by using a front-end loader. As composting progresses and microbial activity declines, the turning frequency may be decreased. A relatively small cost savings would result if less frequent turnings were required. The majority of the cost associated with turning the windrows is in the acquisition of the windrow turning machine. Because one machine would be needed even though the turning frequency is decreased, reduction of the frequency would only save the labor and fuel costs associated with turning.

Currently, it is uncertain if NC degradation occurs through an aerobic or anaerobic mechanism. If NC degradation is shown to occur aerobically, the oxygen supplied with daily turnings may be supplemented with forced aeration. The aeration system would be constructed by placing a series of perforated corrugated pipes in a bed of woodchips under each windrow and connecting the ends of the pipes to blowers. The windrow turner would then be adjusted to pass over the aeration tubing. The need for supplemental aeration could be evaluated in the pilot study. If it is found during this pilot study that supplemental aeration is not necessary, the cost and operating complication associated with its implementation will be avoided.

4.3.4.2 Windrow Monitoring

Windrows would be monitored for temperature, percent oxygen, percent moisture, pH, and NC concentration. Monitoring frequencies are presented in Table 4-4.

Temperature would be monitored using thermocouples in conjunction with a landfill probe and a hand-held digital controller. Temperature would be monitored at six points along the

Table 4-4

Windrow Monitoring Frequency

Parameter	Frequency	Number of Locations/Windrow
Temperature	Daily	6
Percent Oxygen	Daily	6
Percent Moisture	Two times/week	4
pH	Two times/week	3
Explosives Concentration	Day 0 and 30	Composite of four samples

length of the pile before turning. The number of monitoring locations may be increased if a large variability is seen between the sampling points.

The oxygen level would be monitored daily prior to turning using a hand-held oxygen meter. The meter would be attached to a probe inserted into the windrow. Air would be manually drawn through the probe with a hand pump until a steady oxygen value is obtained.

Percent moisture would be monitored twice weekly. In each case, four samples per windrow are needed (with three replicates each). Water would then be added to the windrow as needed to maintain the required compost moisture content. Three pH samples per windrow would be taken at the same time as the moisture samples.

Assuming that process kinetics will be developed during a pilot study such that only initial and final concentrations need to be determined, NC concentrations would be analyzed at a laboratory on days 0, 15, 25, and 30. In each case, one composite sample would be made from four discrete points and sent off site for analysis.

As discussed in Subsection 4.2, numerical criteria for NC treatment may not apply. Rather, demonstration of nonreactivity may be necessary. Two approaches may be considered for accomplishing this objective. The first would be to subject samples of finished compost to a standardized reactivity test, such as those used in the reactivity testing program.

The second approach would be to use the relationship between NC level and reactivity (see Figure 3-1) as a basis for using the analysis for extractable NC as the only performance parameter. It is recommended that a correlation between the two approaches be developed during the pilot study such that only NC analysis would be required in the full-scale treatment process.

4.3.4.3 Windrow Removal and Disposition

After the composting period is complete, a front-end loader would be used to remove the finished compost from the windrows and remove it to a staging area outside of the structure. From the staging area, a covered dumptruck would transport the finished compost to its final disposition. It is assumed that the compost would have been treated to meet reactivity criteria and could be used on site as a soil amendment. Options for final compost disposition may be developed in subsequent projects. Because of the increase in volume that occurs when the amendments are added for composting, there would be more finished compost than NC by volume.

4.4 FACILITY DESCRIPTION

4.4.1 General

This subsection describes a conceptualized compost facility used to treat NC fines.

These facilities have been developed assuming that RCRA facility standards will not be applicable to the facility, since the excess NC fines are not considered to be wastes by the facility and the compost process is intended to reduce their reactivity for use as a soil amendment.

4.4.2 Site Layout

The composting facility centers on an asphalt pad where the windrows would be constructed. A pre-fabricated structure covers the area to control dust. A conceptual site layout is presented in Figure 4-5.

4.4.2.1 Compost Area

The composting area would be paved with asphalt. The pad would be designed to be structurally sound beneath the weight of operating equipment.

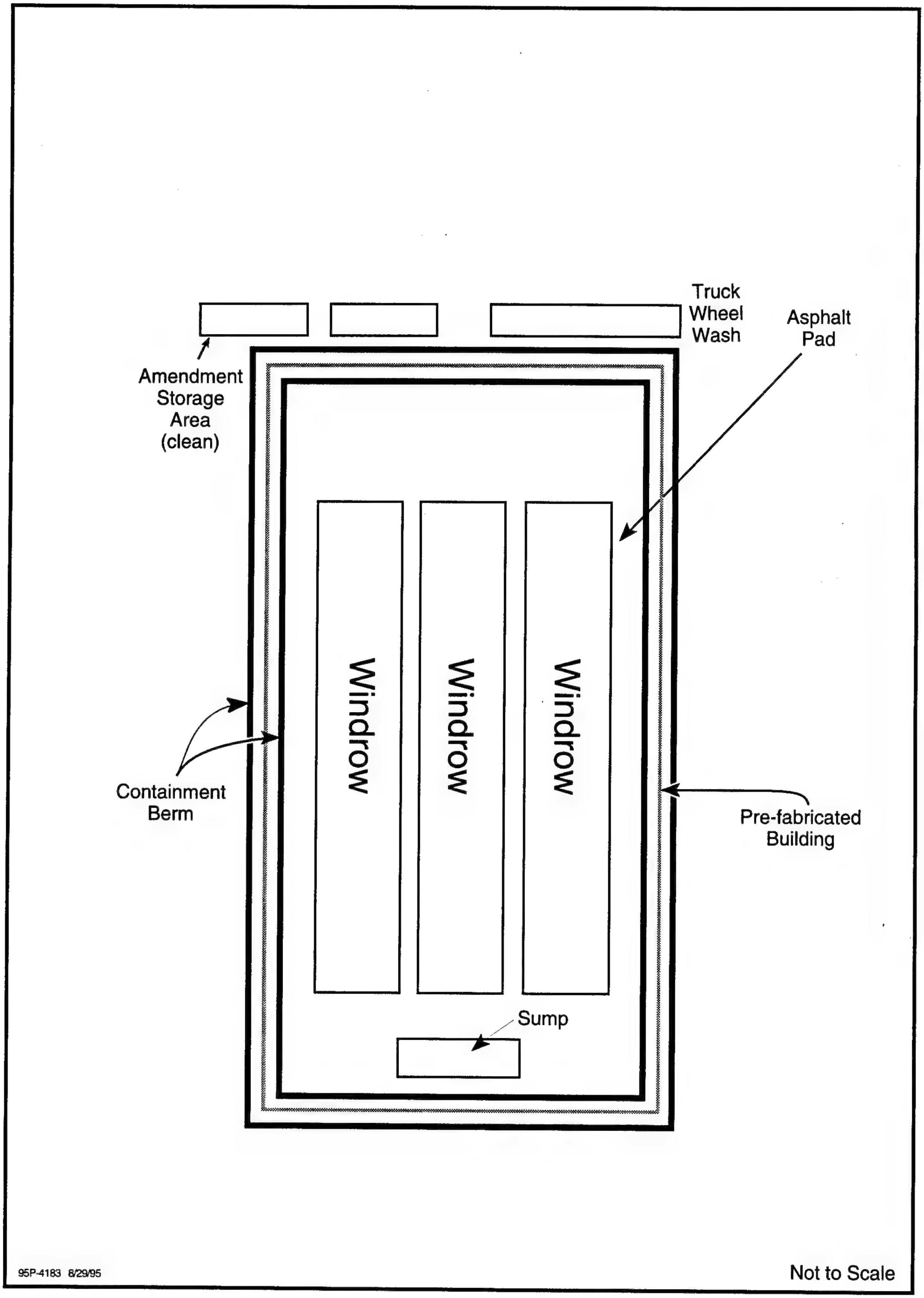

FIGURE 4-5 SITE LAYOUT FOR WINDROW FACILITY

The paved area would be surrounded by a containment berm. A sump would be located at one end of the pad to contain any excess water spilled or generated inside the building. The area would also be covered with a temporary structure.

4.4.2.2 Site Support Facilities

The site support facilities would be minimized to reduce costs. The support facilities consist of a trailer and a storage shed for equipment. The trailer would contain equipment for on-site process monitoring and maintenance, and first aid equipment. It is assumed that additional support (e.g., sanitary, office, and other facilities) would be available on the operating facility (i.e., RAAP).

4.5 FACILITY DESIGN AND OPERATING REQUIREMENTS

4.5.1 Equipment List

The major equipment list for the facility is presented in Table 4-5. This list includes all major operating equipment required for materials handling, and windrow construction and turning.

4.5.2 Construction Requirements

Facility features include:

- Site Preparation
  - Clearing and grubbing.
  - Excavation for area system.
  - Subgrade preparation.
  - Final site grading.
  - Seeding and mulch.

Table 4-5

Major Equipment List for Windrow System

Equipment	Quantity Required	Capacity/ Dimensions	Type
Backhoe	1	1 yd^3	Caterpillar 225 or equivalent
Dump Truck	1	12 yd^3	--
Front-End Loader	2	2 yd^3	Caterpillar 926 wheel loader or equivalent
Water Pump	1	10 gpm	Centrifugal; explosion-proof
Windrow Turner	1	14 ft base	Sandberger SP-100 or equivalent

- Asphalt Work
  - Site paving (6 inches crushed gravel, 6 inches asphalt).
  - Containment berm.
- Building
  - Pre-fabricated structure to prevent precipitation from reaching the windrows and for site security.

4.5.3 Operating Requirements

4.5.3.1 Control Parameters

The primary control parameters for windrow composting would be:

- Windrow-turning frequency.
- Water addition.
- Operation of supplemental aeration system (if used).

Windrow-turning frequency determines the rate of oxygen addition as well as lowering of the windrow temperature. Water addition would be used to maintain an optimal moisture content and also slightly lower the compost temperature.

4.5.3.2 Utility Requirements

The primary on site utilities required for operation would be:

- Water for addition to compost and for equipment decontamination.
- Diesel fuel for heavy equipment.
- Electric power for lighting and equipment.

4.5.3.3 Personnel

The size of the facility would require a small crew of operators and technicians. Because of the limited number of employees, they must be versatile individuals, trained in heavy

equipment operation, compost monitoring, facility maintenance, reporting, and other tasks required during windrow operation. NC analysis and/or reactivity analysis would be conducted at an off-site laboratory.

4.6 ECONOMIC ANALYSIS

The applicability of windrow composting as a viable alternative for the treatment and reuse of NC fines will be partly determined by its relative cost. Cost information is available for conventional (MSW and sludge) composting systems. Additionally, previous field demonstrations have provided some cost estimates for windrow composting of contaminated soils[11,29].

In this subsection, potential costs associated with windrow composting of NC fines are developed. These estimated costs are based on the processing equipment and parameters described in Subsections 4.4 and 4.5. This analysis is intended to evaluate and illustrate the potential economic feasibility of windrow composting as a treatment technology.

4.6.1 Capital Costs Estimate

4.6.1.1 Methodology and Assumptions

Capital costs for the windrow system were developed using conventional construction cost estimating procedures. Facility dimensions, material requirements and quantities, and methods of construction were based on a standard construction cost reference[30]. Unit prices for equipment were obtained either from standard references for conventional equipment, or from vendor quotes for agricultural or specialized compost equipment. Table 4-6 presents major items included in the capital cost estimate.

4.6.1.2 Geographic/Site-Specific Assumptions

The conceptual technical approach developed in this report is applicable to a variety of sites and situations. The specific geographic, meteorological, and environmental conditions, and

Table 4-6

Major Items Included in Potential Capital Costs for NC Windrow Composting System

Equipment • 1-yd^3 backhoe. • 12-yd^3 dump truck. • 2-yd^3 front-end loader. • Windrow turner. • Water pump (for sump). • Monitoring equipment. Sitework • Clearing and grubbing. • Bulk excavation. • Grading. • Paving. • Seeding and mulching.	Buildings and Structures • Compost structure. Mechanical/Piping • Site drainage and storm runoff control. Electrical • Equipment power distribution. • Site lighting.

location-specific factors at any given site, however, may affect system costs. For this analysis, the following generalizations were made:

- Site costs were developed based on level topography. Substantial deviations in land elevation would increase the cost for site preparations.

- The composting site was assumed to be located in close proximity to the NC fines settling pit/tanks to minimize hauling requirements. If a close proximity is not possible, transportation costs for NC fines would increase.

- Land necessary for the composting facility was assumed to be supplied by RAAP. No land costs have been included.

- Necessary site utilities (e.g., electric and water) are assumed to be provided by RAAP. Costs for providing utilities to the site are not included.

- The potential cost for permitting or regulatory approval of the composting treatment facility are not included in these estimates.

- Disposal costs for finished compost have not been included. These may be considered under a subsequent investigation. Finished compost may be considered as a valuable soil amendment. This value has also not been included.

- A 20-year project life was assumed.

- Major equipment was assumed to have a 10 year service life. Replacement costs for all heavy equipment are included at year 10 of operation. The present worth of the salvage values for equipment at year 10 are also included. An escalation rate of 3.5% has been used in calculating present worth.

4.6.1.3 Contingency

A contingency factor (generally as a percentage of total capital) is conventionally added to various types of cost estimates to allow for unknown and unforeseeable factors or changes, which may develop. Costs in this report are presented with a 15% contingency factor.

4.6.1.4 Project Financing

It has been assumed that construction funds would be obtained through government appropriations on a fiscal year basis. Therefore, no costs associated with project financing are included.

4.6.1.5 Results

Potential capital costs associated with the windrow composting facility are presented in Table 4-7. Within the previously discussed constraints, the total capital costs are estimated at $1,529,000.

4.6.2 O&M Cost Estimate

4.6.2.1 Methodology and Assumptions

Estimates of potential O&M costs were developed based on the conceptual layouts presented in Subsection 4.3. The following description presents the basic procedure used in developing this estimate.

The potential materials and materials handling requirements were estimated from the conceptual process description. Productivity and fuel consumption rates developed specifically for contaminated soil windrow composting[30] were used to estimate total operational hours and fuel for such activities as windrow construction, windrow turning, and windrow dismantling. Manpower requirements for these activities, including equipment operators and laborers, were estimated based on previous operating experience. Analytical costs are based on NC analysis only, assuming that NC concentration will be correlated to reactivity during the pilot study. From these estimates, annual operating costs associated with compost production were estimated using the unit costs presented in Table 4-8.

The total cost of amendment materials was estimated using quantities presented in Subsection 4.3. Unit prices are based on previous experience[11].

Table 4-7

Estimated Capital Costs for Windrow Composting System

Item	% Markup	Cost ($)
Equipment		487,600
Site Preparation		4,200
Structure (pad and shelter)		125,600
Mechanical/Piping (drainage and runoff control)		14,000
Electrical		93,000
First Subtotal Capital		**724,400**
Project Construction Facilities	@ 8%	58,000
Mobilization/Demobilization	@ 1.1%	8,000
Construction Equipment, Consumable Items	@ 5%	36,200
Fees	@ 1.5%	10,900
Present Worth Value of Equipment Replacement		154,500
Present Worth Value of Salvaged Equipment		(15,700)
Second Subtotal Capital		**976,300**
General and Administrative Overhead Costs	@ 9.5%	92,700
Third Subtotal Capital		**1,069,000**
Contractor Markup and Profit	@ 10%	106,900
Fourth Subtotal Capital		**1,175,900**
Contingency	@ 15%	176,400
Construction Quality Assurance/Oversight	@ 15%	176,400
Total		**1,529,000**

Table 4-8

Operation and Maintenance Unit Costs

Area	Unit Costs ($)
Labor[a]	24/hour
Electric	0.065/Kwhr
Diesel Fuel	1.25/gallon
Amendments[b]	20/yd^3
Analytics (off-site)[c]	100/sample

[a] Does not include overhead costs.
[b] Based on a previous experience for delivered amendments(11).
[c] Based on previous experience.

Ultimately, the goal of composting NC fines would be to convert nonrecoverable excess NC into a usable product such as agricultural soil amendment, either for sale or for free distribution. If suitable markets for the finished product are not available, disposal may be necessary. In this cost estimate, the economics of final compost use/management or disposal were not included.

Maintenance was estimated at 3% of the total capital cost annually. For consistency with the operations costs, annual maintenance costs were divided by the number of cycles per year and presented on a per cycle basis in Table 4-9. This represents the scheduled preventive maintenance on all mechanical equipment (e.g., oil change and fluids change) and other routine activities (e.g., equipment servicing and calibration) required to maintain full scale operation of the facility equipment.

A 20-year project length was assumed in these analyses.

O&M costs were converted to present worth assuming a 3.5% escalation factor and a 20 year project life. Present worth calculations assumed equal annual O&M costs each year for 20 years and are presented in 1995 dollars. Capital costs are in terms of present value. As with the capital costs, a 15% contingency was applied to the annual O&M costs.

4.6.2.2 Results

The windrow composting system estimated O&M costs are presented in Table 4-9. The total annual O&M costs, including contingency, are estimated to be $347,000. Assuming a 20 year project life and a 3.5% escalation factor, the present worth O&M cost for the project duration is $4,931,900.

Table 4-9

Estimated Annual O&M Costs for Windrow Composting System

Item	% Markup	Cost ($/cycle)
Power		600
Amendments		2,200
Fuel		1,600
Labor		10,500
Analytics (off-site)		4,800
Maintenance (@ 3% of total capital annually)		4,500
First Subtotal O&M		**24,200**
Engineering, Procurement, Administrative, and Legal	@ 15%	3,600
Contractor Markup and Profit	@ 10%	2,400
Second Subtotal O&M		**30,200**
Contingency, Oversight, Profile, etc.	@ 15%	4,500
Total O&M per Cycle		**34,700**
		($/year)
Total O&M per Year		**347,000**
20-Year Present Worth Value (@ 3.5% escalation factor)		**4,931,900**

4.6.3 Total Project Cost

The total 20-year project cost of the windrow composting system, as presented herein, is estimated to be \$6,460,900. This corresponds to a cost of \$1,000/ton or \$310/yd^3 of NC. A summary of the contributors to total cost is found in Table 4-10.

4.6.4 Potential Cost Sensitivities

Potential cost sensitivities which may be associated with the NC windrow composting facility include the following:

- The facility size, and thus facility costs, is largely dependent on process kinetics. Appropriate kinetics associated with the NC fines composting process will be determined during a pilot study. Based on these results, the overall project costs may be increased or decreased.

- NC fines loading rates will also effect the facility size, and therefore overall project costs. Costs may be lowered if NC fines loading rates higher than 35% are achievable.

- Optimization of process parameters may serve to decrease treatment time and therefore decrease project costs.

- If the projected facility life changed significantly from the assumed 20 year life, costs would be effected.

4.6.5 Cost Comparison with Soil Composting

The total present worth project cost for composting 20,000 tons of explosives soil in 5 years was estimated to be approximately \$200/ton of soil(11) compared with \$1,000/ton for NC fines. Although the cost of NC fines composting appears to be somewhat higher on a per ton basis than the costs previously developed for explosives-contaminated soils(29), the following factors must be considered when comparing the costs:

Table 4-10

Total Estimated 20-Year Project Cost for Windrow Composting System

Item	Cost ($)
Total Capital	1,529,000
Total 20-Year O&M (P/W)	4,931,900
Total 20-Year Project Cost (P/W)	6,460,900
NC Fines Treated in 20 Years (Tons)	6,400
Cost Per Ton of NC Fines	1,000
Cost Per yd^3 of NC Fines[a]	310

[a] Assuming NC fines density of 620 lb/yd^3.

- The soil composting system was based on a 4,000 tons/year throughput and the NC fines system was based on 325 tons/year. As was demonstrated in the Windrow Composting Engineering/Economic Evaluation[11], the cost per ton of soil processed decreased with increasing throughput. Even for equivalent materials, therefore, the cost per ton of material would be greater for a 325 ton per year facility than for a 4,000 ton per year facility.

- Because the density of NC fines is much less than the density of soil, the cost per yd^3 of material may be a better measure for comparison. Using a density of 2,300 lb/yd^3 for soil and 620 lb/yd^3 for NC fines, the costs on a unit volume basis are $\$230/yd^3$ for soil and $\$310/yd^3$ for NC fines.

- The soil composting costs were estimated using kinetic information obtained during a field optimization demonstration[11]. No corresponding data are available for the NC fines.

SECTION 5

RECOMMENDED PILOT STUDY TEST APPROACH

5.1 OBJECTIVE

Based on the results of previous testing[8], the reactivity testing program conducted by RAAP (Appendix B), and this preliminary process/economic analysis, it appears that composting may have promise for converting NC fines into a beneficial finished compost. In order to further develop this technology, a pilot test, which combines current knowledge from the above noted sources, and which focuses on identifiable technology developmental needs, appears warranted.

The specific objective of this pilot demonstration would be to demonstrate that windrow composting can be used to reduce the reactivity of NC fines and to determine the percentage of NC fines that can practically be included in the compost formulation for cost effective treatment.

5.2 TECHNICAL ISSUES REQUIRING INVESTIGATION

The overall key technical issues to be addressed in the pilot study would be:

- Verifying that NC fines composting is a viable treatment method.
- Determining the highest percentage of NC fines usable within the mixture to be composted in a windrow, while staying below the reactivity limits.
- Determining the composting period necessary to achieve the desired NC destruction.

- Evaluating the need for adding additional carbon sources (amendment supplementation) after temperatures have dropped in the windrow to prolong the composting period and achieve additional NC degradation.

- Maintaining environmental parameters (i.e., moisture, temperature, pH, and oxygen) such that transformation of contaminants is optimized and the potential for reactivity of NC fines is minimized.

- Determining the need for forced aeration to supplement the oxygen provided from windrow turning during the composting process.

- Determining safe materials handling procedures for initial NC fines/compost mixing and compost pile maintenance.

- Determining a reliable analytical method for determining when the NC fines/compost mixture becomes non-reactive.

- Evaluating final compost compaction.

5.3 RECOMMENDED APPROACH

Four NC windrows would be used to investigate the areas described in Subsection 5.2. Two composting cycles, each consisting of two windrows, would be used. Initial testing would be conducted at 10% NC by weight on an as mixed basis, which is considered to be a safe level based on the reactivity testing program. The second cycle would contain one windrow at 20% and one at 35% by weight on an as mixed basis. Efforts would then be made to extend the process to higher NC loadings in the interest of process economics. During the first cycle, one windrow would include forced aeration as well as mixing with a windrow turner and one windrow will be aerated only through use of the windrow turner. Based on the findings of the first cycle, the best way to aerate the windrows during the second iteration would be determined. All windrows would be turned daily and tested periodically for NC concentration, moisture content, pH, oxygen levels, and temperature.

5.4 TEST SUBTASKS

The recommended pilot test would consist of five subtasks as follows:

Subtask 1 - Task Preparation

- Site selection.
- Selection of windrow turner and parameter monitoring/controlling equipment.
- Hazard Safety Analysis of windrow turner.
- Preparation of Test Plan.
- Preparation of Site Safety and Health Plan.
- Disclosure of plans for field demonstration to appropriate agencies.
- Identification of base (asphalt, liner, etc.) requirements for NC windrow study.
- Procurement of required materials and equipment.

Subtask 2 - Site Preparation

- Construction of appropriate facility for windrow pilot test.
- Preparation and analytical testing of NC fines to be used.

Subtask 3 - Test Period

- Refinement of compost recipe.
- Preparation of mixtures to be composted.
- Windrow operation.

- Windrow monitoring.

- Data reduction and analysis.

Subtask 4 - Site Restoration

- Equipment would be decontaminated in accordance with provisions of the EPA, state and host installation requirements. Any decontamination washwater remaining at the end of the pilot study will be placed in a portable plastic tank, filtered, and blended into the RAAP wastewater treatment facilities.

- If composting proves to be a successful treatment method and yields non-reactive materials, the finished compost would be disposed of as a soil amendment. Quantities that cannot be used as a soil amendment would be landfilled. Any NC-containing compost, which has not been rendered nonreactive, will be disposed of as a characteristic waste.

- The temporary structure and asphalt pad would be decontaminated with provisions of the EPA, state and host installation requirements. The temporary structure would then be dismantled and removed. All disturbed areas would be regraded and revegetated to restore the areas to their original condition.

Subtask 5 - Reporting

A technical report would be prepared that summarizes all project activities, analytical procedures, results, conclusions, and general recommendations for system optimization and design.

5.5 MATERIALS AND METHODS

5.5.1 Base and Enclosure

The composting study would be conducted on a bermed asphalt pad. The pad would be designed to be structurally sound beneath the weight of operating equipment.

The paved area would be surrounded by a containment berm. A sump would be located at one end of the pad to contain any water generated within the building. A temporary structure would cover the composting area to control dust.

5.5.2 Windrow Turner

A conventional windrow turner would be used to aerate and mix the windrows. One potential candidate would appear to be the Model K-W 614 manufactured by Resource Recovery Systems of Nebraska. This unit has been used for pilot composting of explosives-contaminated soils at UMDA. A variety of comparable machines are available. Since the time of the UMDA demonstration, smaller, more lightweight, and less expensive machines have entered the market, and may offer operating or economic advantages. In particular, economic advantages may be seen in using these smaller windrow turners.

As suggested in Subsection 4.3.3, a Hazard Safety Analysis should be conducted for any candidate equipment, which has the potential to impart shock, friction, or thermal stimuli to the NC. This analysis should consider the specific characteristics of the machine as well as the reactivity characteristics of bulk NC fines as the most conservative scenario.

5.5.3 Materials Handling

A front-end loader would be used to transport small quantities of materials. A dump truck would be used for transport of larger volumes of materials, such as NC fines. Smaller scale materials handling activities would be performed with hand tools such as rakes, shovels, and pitchforks.

A front end loader would be used to layer the amendments and soil used to construct the windrows. After these materials have been placed into a windrow, the windrow turner would be used to mix them. As part of the pilot study, the appropriate moisture level

required to safely handle the NC fines during the mixing operation would be determined through a Hazards Safety Analysis.

5.5.4 NC Fines

NC fines from the settling pit would be used in the pilot study. During preparation of the pilot study test plan, quantities to be used in each windrow and methods for obtaining representative, homogenous materials would be determined. Excess water from NC fines would be drained into the settling pits prior to transport. Results of the Hazards Safety Analysis would be used to determine the appropriate NC fines moisture content.

5.5.5 Amendments

For the purpose of this pilot study, amendments would be any materials included in the mixture to be composted in addition to the NC fines. They may include bulking agents that provide porosity (wood chips or shavings), carbon sources (animal waste, straw, etc.), and specialty materials, such as bacterial inocula or fertilizer. The selection criteria used for incorporating specific amendments have been documented[30]. Compost mixtures were developed considering the general desired properties of compostable mixtures, the known properties of NC waste, and the types of potential compost ingredients available in the vicinity of RAAP. Although these mixtures were developed based upon their general suitability as a compostable matrix, no testing was conducted under this task order to confirm their suitability. It is recommended that amendment mixture compostability testing (heating trials and respiration testing, coupled with supporting physical/chemical analyses) be conducted on these (and, if necessary, other) mixtures to select the final mixture(s) for pilot testing.

5.5.6 Amendment/NC Fines Mix Preparation

Amendments and NC fines to be included in each mixture to be composted would be measured volumetrically using a calibrated container and would be weighed using a calibrated scale. The bulk density of each component would be determined prior to mixture preparation. Actual mass measurements would be compared with the mass values computed from measuring volumes and bulk density to evaluate the accuracy of using volumetric measurements alone during the full-scale treatment process.

The mixtures would be prepared by layering the individual amendments in the shape of a windrow. The components would be mixed using the windrow turner. As discussed in Subsection 4.3.3, the pilot study should address the appropriate NC fines moisture content required to safely mix the NC fines with the amendments. To accomplish this, a Hazards Safety Analysis would be performed as part of the pilot study.

5.5.7 Temperature Monitoring

Temperature within the windrows would be monitored daily by hand using a landfill probe and hand-held meter. Temperature readings would be recorded daily.

5.5.8 Temperature Control

Temperatures would be maintained between 50 and 55 °C, if possible. If temperatures are found to fall below the desired range before the composting period is complete, supplemental amendments may have to be added to increase microbiological activity, subsequently raising the temperature into the desired range.

5.5.9 Oxygen Monitoring

Interstitial oxygen would be monitored using a hand-held probe and meter.

5.5.10 Oxygen Control

During the first composting iteration, oxygen in one windrow would be supplemented with forced aeration in addition to the oxygen received during daily windrow turning. The second windrow would receive oxygen only via windrow turning. Comparison of NC degradation for these two initial windrows would determine the need for supplemental oxygen in subsequent windrows.

5.5.11 Moisture Monitoring and Control

Moisture would be monitored throughout the pilot study to ensure the compost is maintained at safe moisture levels. An appropriate method for moisture content evaluation will be determined during preparation of the pilot study test plan. When moisture falls below the preselected range, water would be added directly to the mixture. This value would vary depending on the nature of the amendments, but the safety criterion of maintaining no less than 25 to 30% moisture at all times would be paramount. The total volume of water added would be monitored and recorded in the field log book. Care would be taken during water addition to generate no runoff.

5.5.12 pH Monitoring and Control

pH would be monitored using grab samples from each windrow. The method to be used for pH analyses would be determined during preparation of the pilot study test plan. It is not anticipated that pH adjustment would be necessary during the composting process. Experience in explosives-contaminated soil composting indicated an increase in pH during the composting process. This increase, however, was seen to have no detrimental effect on the composting process[11].

5.5.13 Sampling

Samples for chemical characterization and reactivity would be taken from the compost mixture using a soil auger. Samples would be removed from selected locations at each time point and shipped to the analytical laboratory designated by overnight freight using chain-of-custody procedures. Time points for analysis would be specified in the pilot study test plan.

5.5.14 Analytical and Reactivity Testing

Prior to initiation of the pilot study, an appropriate analytical method should be determined for NC concentration. Previous studies[8] utilized USATHAMA Method LY02, modified for the extraction and analysis of compost. Since this method analyzes for the nitrate ion, other nitrogenous compounds naturally occurring in the amendment ingredients may affect the accuracy of the analysis. The accuracy of this method, as well as other analytical methods, would be determined.

During the pilot study, reactivity testing of the compost is recommended in conjunction with chemical characterization at each sample time. The results of this reactivity testing could be used to correlate NC concentration with reactivity or, alternatively, to correlate a treatment period at specified operating conditions with reactivity. After this correlation is established, routine reactivity testing would not be necessary.

5.5.15 Microbial Enumeration

Microbial enumeration methods would be used to estimate the number of aerobic microbes at selected times during the process. These enumerations would be used in conjunction with temperature and oxygen readings as an indicator of biological activity. An attempt would be made to correlate the microbial enumeration data to NC analytical and reactivity testing to determine whether the NC degradation rate reflects the overall population level. It may

also be desirable to estimate the number of anaerobic microbes to determine the relative contribution of anaerobic degradation to the composting process.

5.5.16 Safety

Specific safety requirements would be addressed in a Site Safety and Health Plan in compliance with OSHA 29 CFR 1910 and 1926 (OSHA General Industry and Construction Standards, respectively), 40 CFR 260-270 (EPA Solid Waste Standard), and DOD 6055.9-STD (DOD Ammunition and Explosives Safety Standards). All appropriate safety equipment will be maintained on site. A telephone would be placed in the site trailer to serve as a direct link to emergency personnel should an emergency occur.

5.5.17 Site Facilities

An office trailer and portable toilet would be maintained at the pilot study site for use by project personnel. The windrow pilot study would be conducted on an asphalt pad covered by a temporary structure.

5.5.18 Compost Residue Disposal

At the end of each windrow test, the nonreactive compost residue produced would be disposed of appropriately. Disposal options may be evaluated in a subsequent study. Any material that has not successfully treated would be properly disposed of as a characteristic waste.

5.5.19 Decontamination Water Disposal

Surfaces of equipment that have come in contact with NC fines or compost would be washed and the water collected in a portable plastic tank. This water would then be filtered and blended into the RAAP wastewater treatment plant influent.

5.5.20 Site Restoration

Equipment used on the site, as well as the temporary structure and pad, would be decontaminated in accordance with provisions of RAAP and EPA. All disturbed areas would be regraded and revegetated to restore the areas to their original condition.

5.6 TEST CONDITIONS

5.6.1 Constant

5.6.1.1 NC Fines

Because it is essential that NC fines be kept wet at all times to prevent ignition, long term storage at the compost site would be difficult from the standpoint of containment and moisture control. As a result, NC fines would remain in the settling pits until needed for windrow construction. At the time of windrow construction, the necessary quantity of NC fines would be removed from the pit and allowed to drain to the appropriate moisture content. The free liquid would be drained back into the pit from which the NC was excavated. The NC could then be transported to the excavation area by dump truck.

5.6.1.2 Individual Amendment Characteristics

In order to ensure accurate data interpretation, the key characteristics of each individual amendment in the selected mixture would be maintained as constant as possible over the course of the pilot testing. This would be done by obtaining fresh amendments from the same source for each test.

5.6.1.3 Temperature

The results of the BAAP field demonstration have indicated that thermophilic temperatures result in greater NC reduction[8]. Consequently, the sought after temperature range for the windrow would be 50 to 55° C. Temperature profiles are expected across the windrow

depth. The temperature range sought in these tests would be maintained based on an average temperature for the windrow. If necessary, the windrow turning frequency would be increased to ensure that the maximum temperature at any given point does not exceed 65° C.

5.6.1.4 Moisture

The BAAP field demonstration clearly demonstrated the importance of adequate moisture[8]. The composting process, however, did not appear (within the constraints of the available data) to be sensitive to moisture between the range of 40 to 45% moisture and saturation. For the planned pilot studies, the moisture content in all windrows would be maintained at a minimum of 25 to 30% moisture at all times.

5.6.2 Variable

5.6.2.1 NC Fines/Amendment Mixture Ratio

The NC fines percentage in the windrow mixtures to be composted is a key test variable for the pilot study. The pilot study would include a total of 6 piles, two each at 10, 20, and 35% NC by weight. As was discussed in Subsection 4.6, the percentage of NC contained in the compost would have a large effect on total project cost. Therefore maximizing the NC fines loading within safety constraints would be a key issue to be addressed in the pilot study.

5.6.2.2 Windrow Aeration

During the first windrow composting iteration, both windrows would be turned daily with the windrow turner to add oxygen to the compost. One windrow would also be oxygen supplemented with forced aeration. Oxygen levels would be monitored daily with hand held probes and oxygen sensors. By using the oxygen level measurements and NC degradation data from these initial windrows, the need for supplemental oxygen to achieve the desired NC degradation can be determined.

5.6.2.3 Amendment Addition

Extending the period of active composting may prove critical to achieving acceptable NC fines destruction. If necessary, active composting would be restarted by adding supplementary carbon sources after the initial carbon sources have been depleted and temperatures have dropped. The necessity for amendment supplementation would be determined by the NC fines degradation kinetics. As discussed in Subsection 4.2, the kinetics of NC fines degradation are somewhat uncertain and therefore the projected treatment period cannot be firmly established. Determination of these kinetics would be a key part of the pilot study.

5.6.3 Planned Tests

5.6.3.1 Windrow Test

Four pilot-test windrows are recommended. The tests would be run two at a time for two iterations and each would consist of approximately 50 yd^3 of material to be composted. Because of the uncertainty of the process kinetics and thus the treatment period, data from the first two windrows would be used to determine the treatment period for subsequent tests during the pilot study. The individual tests would differ as shown in Table 5-1.

5.6.4 Data Recording and Analysis

Data management for the composting test would be accomplished by a computerized data management system. Daily operating data would be manually entered into, and maintained by, the system in a form suitable for subsequent manipulation and analysis. Data to be managed by the system may include temperature, pH moisture content, and oxygen readings.

The difference in NC reduction between the various windrows would be statistically analyzed to determine the controlling process variables and optimum operating conditions.

Table 5-1

NC Fines Concentration in Windrows Recommended for Pilot Study

Windrow	NC Fines (% by mass)
1 (Aerated)	10
2 (Unaerated)	10
3	20
4	35

SECTION 6
CONCLUSIONS

The objective of this report was to summarize the results of the NC fines compost hazards analysis, conducted by RAAP, analyze the feasibility of NC fines composting under nonreactive loadings, and develop recommendations for conducting a pilot study. Based on previous NC studies[7,8], NC fines appear to be degradable by the composting process. The hazards analysis conducted by RAAP showed that NC fines can be incorporated into a nonreactive compost mixture. NC fines compost loading rates between approximately 10 and 35% at 30% moisture meet the safety requirements from the RAAP hazards analysis and are within the composting parameters included in the BAAP composting study. Because NC fines are reactive, but not toxic, no numerical performance standards are available for NC fines. The performance standard used for purposes of this study was 10% NC fines. At this concentration, the RAAP hazard analysis showed the NC fines compost mixture to be nonreactive under all moisture conditions.

Using a basis of 35% NC fines and a quantity of 1790 lbs/day of NC fines on a wet basis, within the constraints described in Subsection 4.6, the total estimated capital cost is $1,529,000. The present worth of the annual O&M for a 20 year project life was estimated to be $4,931,900. The overall 20 year project cost would then be $6,460,900. The total capital and O&M costs corresponds to a cost of $1,000/ton of NC fines or $310/yd^3 of NC fines.

The treatment costs could potentially be decreased with improved kinetic data and increased NC fines loadings in the compost. A pilot study is recommended to verify the assumptions included in the cost analysis. Specifically, the pilot work should verify NC fines loadings, process kinetics, and operating parameters.

SECTION 7

REFERENCES

1. Shreve and Brink, 1977. Chemical Process Industries, 4th Edition, Chapter 22, McGraw Hill.

2. U.S. Army, September 1984. Military Explosives, Department of the Army Technical Manual TM 9-1300-214.

3. Hercules Incorporated, 1979. Nitrocellulose, Chemical and Physical Properties.

4. Meyer, Rudolf, 1987. Explosives, Third Edition, VCH Publishers, New York.

5. USEPA, Office of Drinking Water, September 1987. Nitrocellulose Health Advisory, Final Report, prepared for U.S. Army Medical Research and Development Command, Report Number PB90-273541.

6. Kim, B.Y., and J.K. Park, November 1993. "Comprehensive Evaluation and Development of Treatment Technologies for Nitrocellulose Fines in Process Wastewater", Nitrocellulose Fines Separation and Treatment Workshop Proceedings, U.S. Army-Purdue University.

7. Atlantic Research Corporation, 1986. Composting Explosives/Organics Contaminated Soils, Final Technical Report, prepared for USATHAMA, Report Number AMXTH-TE-CR-86077.

8. WESTON, 1989. Field Demonstration-Composting of Propellants-Contaminated Sediments at the Badger Army Ammunition Plant (BAAP), Final Report, prepared for USATHAMA, Report Number CETHA-TE-CR-89061.

9. WESTON, 1988. Field Demonstration-Composting of Explosives-Contaminated Sediments at the Louisiana Army Ammunition Plant (LAAP), Final Report, prepared for USAEC, Report Number AMXTH-IR-TE-88242.

10. WESTON, 1991. Optimization of Composting for Explosives Contaminated Soil, Final Report, prepared for USAEC, Report Number CETHA-TS-CR-91053.

11. WESTON, 1993. Windrow Composting Demonstration for Explosives-Contaminated Soils at the Umatilla Depot Activity, Hermiston, Oregon, Final report, prepared for USAEC, Report Number CETHA-TS-CR-93043.

12. Wendt, T.M., and A.M. Kaplan, 1976. "A Chemical-Biological Treatment Process for Cellulose Nitrate Disposal,", Journal WPCF, 48, 4, 660.

13. Riley, P.A., D.L. Kaplan, and A.M. Kaplan, 1984. Stability of Nitrocellulose to Microbial Degradation, U.S. Army Natick Research and Development Center, Technical Report Number NATICK/TR-85/04.

14. Siu, R.G.H., et al., 1949. "Specificity of Microbiological Attack on Cellulose Derivatives." Tex. Res. Jour., 19, 484 (UR).

15. Siu, R.G.H., 1951. "Microbial Decomposition of Cellulose with Special Reference to Cotton Textiles." Reinhold Publishing Corp., New York, NY (UR).

16. Greathouse, G.A., 1950. "Microbial Degradation of Cellulose." Tex. Res. Jour., 20, 227 (UR).

17. Gagliardi, D.D., and Kenny, V.S., 1968. "Microbial Resistance of Textile Resin Systems." Develop. Ind. Microbiol., 9, 189 (UR).

18. Selby, K., 1968. "Mechanism of Biodegradation of Cellulose." In "Biodegradation of Materials." A.H. Walters and J.J. Elphich [Eds.], American Elsevier Publ. Co., Inc., New York, NY (UR).

19. Kaplan, A.M., et al, 1970. "Resistance of Weathered Cotton Cellulose to Cellulose Action." Appl. Microbiol., 20,85 (UR).

20. Kaplan, D.L., 1990. "Biotransformation Pathways of Hazardous Energetic Organo-Nitro Compounds," In Advances in Applied Technology Series, Vol. 4, D. Kamely, A. Chackrabarty and G.S. Omenn [Eds], Biotechnology and Biodegradation International Workshop.

21. Urbanski, T., 1965. "Chemistry and Technology of Explosives, Vol, II." Pergamon Press, New York, NY; PWN, Polish Scientific Publ., Warszawa.

22. Brodman, B.W., and M.P. Devine, 1981. "Microbial Attack of Nitrocellulose," Journal of Applied Polymer Science, 26, 3, 997.

23. Gallo, B., A. Allen, R.L. Bagalawis, C. Woodbury, A. Vang, P. Austin, and D. Kaplan, November 1993. "Microbial Degradation of Nitrocellulose", Nitrocellulose Fines Separation and Treatment Workshop Proceedings, U.S. Army-Purdue University.

24. Duran, M., B.J. Kim, and R.E. Speece, November 1993. "Anaerobic Biotransformation of Nitrocellulose", Nitrocellulose Fines Separation and Treatment Workshop Proceedings, U.S. Army-Purdue University.

25. Hsieh, H.N. and F.J. Tai, November 1993. "Anaerobic Digestion and Acid Hydrolysis of Nitrocellulose", Nitrocellulose Fines Separation and Treatment Workshop Proceedings, U.S. Army-Purdue University.

26. Hercules, Incorporated, Radford Army Ammunition Plant, November 1993. "Personal Communication".

27. Rynk Robert, (Ed.) 1992. "On-Farm Composting Handbook. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

28. WESTON and Hercules, Inc., 1994. Composting of Nitrocellulose Fines-Hazard Analysis, Combined Test Plan, prepared for USAEC.

29. WESTON, 1993. Windrow Composting Engineering/Economic Evaluation, prepared for USAEC, Report Number CETHA-TS-CR-93050.

30. Richardson Engineering Services, Inc. 1988. Process Plant Construction Estimating Standards, Volumes III and IV.

APPENDIX A

SITE VISIT SUMMARY

USAEC
CONTRACT DACA31-91-D-0079
TASK ORDER 0007
COMPOSTING OF NITROCELLULOSE (NC) FINES - HAZARD ANALYSIS

Amendment Selection Site Visit
13-14 December 1993

On Monday 13 December 1993 and Tuesday 14 December 1993, Jonathan Colinson of Woods End Research Laboratory and John Hammell of WESTON visited the Radford, Virginia area in search of compost amendment sources. The objective of the trip was to establish initial contacts with potential suppliers of horse manure, cow manure, alfalfa hay, straw, sawdust, etc. The field team met with several different people over the two day trip, and identified sufficient sources of the desired amendments for the project. The following list summarizes each of the meetings and available waste material, all of which are within a 15 to 20 mile radius of Radford Army Ammunition Plant.

1. **Montgomery County Agricultural Extension**
Christiansburg, VA
Joe Hunnings - phone (703) 674-4111

Jonathan and John explained the reason for the visit and asked if Mr. Hunnings could provide any ideas or contacts for amendment sources in the Montgomery County area. The following bullets summarize his suggestions:

- Sawdust and mulch will be readily available in the immediate area. Hollybrook Sawdust & Mulch (639-4713) provides clean material for less than $20 per cubic yard. Also, the Montgomery County Landfill provides chipped yardwastes and pallets for sale (contact Randall Bowling, the County Engineer, at 382-6928).

- Horse farms are less common, typically on the scale of 20 horses and owners are usually spreading manures on their own fields. Two farms which he recommended were Dori-Dell Stables near Blacksburg, VA and Walnut Springs Stables (phone 953-3155).

- Food processing is virtually nonexistent in the region, although there may be a tomato company in Roanoke, VA.

- Livestock feed is typically produced onsite by individual farmers for their own use. He suspected that alfafa, grass, and clover hays would be available. He said some corn silage may also be found, although typically farmers develop contracts for the sale of the silage prior to growing it.

- Outside of the immediate area, other potential sources may exist such as tobacco industry (2 hours south), apple orchards and cabbage farming (1 hour away), and a regional farmers market in Hillsville, VA (45 minutes south).

2. **Kegley Farms**
Pulaski, VA
Bill Kegley - phone (703) 980-3690

Mr. Kegley owns a farm of over 2000 acres where he raises dairy cows, calves, and sheep. Although he stated that the waste materials he produces could be used on his own farm, he would be willing to negotiate an agreement for purchase of any of the following amendments that he has available:

- baled corn fodder, oat straw, barley straw
- dairy cattle manure mixed with corn fodder
- liquid manure from his lagoon system
- waste or fresh silage

In addition to providing the above amendments, Mr. Kegley was receptive of the idea of allowing the compost mixing to be performed at his farm. Also, he provided his sawdust suppliers name (Dallas Hubbard - Mr. Kegley has phone #) who charges $250 for approximately a 40 cubic yard trailer load of the sawdust.

3. **New River Valley Horse Center**
Christiansburg, VA
Gene Edwards - phone (703) 382-3329

Mr. Edwards operates a 52-stall horse-training and boarding facility which produces a mixture of horse manure and bedding material which he says would be available for the project. The material contains a relatively high proportion of bedding materials (sawdust and straw). If necessary, Mr. Edwards would be willing to transport his manure to the mixing site, as he already has a contract with Virginia Tech to haul the ash created by their coal-burning central heating facility.

4. **Pulaski Furniture Corporation**
Dublin, VA
Jack Martin/Bill Perdue - phone (703) 674-4111

The Pulaski Furniture Company uses the waste sawdust generated by its mill for fuel. They stockpile and cover the material during the summer for use in the winter. Originally, they had been led to believe that the material would remain dry without covering, however, they now have a "mountain" (several thousand cubic yards) of damp sawdust which has been exposed to the elements for three years. They would be glad to provide the material free of charge for the composting project. The material is very fluffy and would likely provide good compost pile aeration.

5. **Livestock Market**

Adjacent to the Pulaski Furniture Company is a stockyard that is used for livestock sales several days per week. The stockyard was closed the days of the site visit, however, a pile of manure was identified that appears to be useless if not a nuisance.

Quantities are limited, but it could probably be obtained for free. The contact name at the stockyard given by Pulaski Furniture is Malcolm Boothe at (703) 980-6914.

6. **New River Resource Authority Landfill**
Radford, VA
Fred Hilliard - phone (703) 639-5743

Mr. Hilliard had indicted that he would be in his office the days of the visit, however, he was not available when Jonathan and John arrive. They received permission to observe the mulch material being generated at the facility. A large tub grinder is used to chip yardwastes and pallet boards. The resulting material is much more coarse than sawdust. The material may be available for free, and there is certainly plenty available.

7. **Virginia Tech University**
Blacksburg, VA
James H. May - phone (703) 231-3868

Jonathan and John met with Mr. May to discuss the composting amendment search and his experience with the applicable regulations affecting composting in Virginia. He explained that there are only 6 yardwaste composting facilities in the state, but the regulations are lenient as long as the material is only yardwaste. If anything other than yardwaste is composted, including manures or foodwaste, then the Virginia municipal solid wastes regulations are applicable. These rules require use of an asphalt or concrete pad equipped with runoff collection and treatment. Mr. May has been attempting to develop a food composting project at VPI, however, he has been unsuccessful in receiving funding which could enable him to construct a facility in compliance with the state regs.

APPENDIX B

SENSITIVITY AND EXPLOSIVE REACTIVITY OF NITROCELLULOSE COMPOST MIXTURES (RAAP)

ALLIANT TECHSYSTEMS

Radford Army Ammunition Plant
P.O. Box 1
Radford, VA 24141–0100

HA–95–R–001
JUNE 28, 1995

Sensitivity and Explosive Reactivity of Nitrocellulose Compost Mixtures
PE–847, Phase I

Final Report
on
Production Engineering Project PE-847

Sensitivity and Explosive Reactivity of Nitrocellulose Compost Mixtures
PE-847, Phase I

by

C. A. Elsea

HA-95-R-001

June, 1995

Prepared by

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REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704–0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	6–28–95	Final Report: 11–22–93 to 5–31–95

4. TITLE AND SUBTITLE

Sensitivity and Explosive Reactivity of Nitrocellulose Compost Mixtures, PE–847, Phase I

5. FUNDING NUMBERS

M1–3–8S797–01–M1–FK
(CLIN:3086AA)

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

HA–95–R–001

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Commander, U.S. Army Environmental Center
ATTN: SFIM–AEC–ETD (Mr. Wayne E. Sisk)
Aberdeen Proving Ground, MD 21010–5401

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SFIM–AEC–ET–CR–95070

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Nitrocellulose (NC) and NC combined with three candidate compost mixtures were tested for reactivity to flame and shock stimuli at various moisture levels. Stabilized NC with a high nitrogen content (>13.15%) provided a safety conservative (ie. more reactive) test program than would be expected with NC fines obtained from manufacturing wastewater streams. Results of Bureau of Mines Deflagration to Detonation Test and standard critical diameter for explosive shock testing determined the maximum NC and minimum moisture requirements for controlling explosive reactivity of compost mixtures. Initiation sensitivity to impact, friction and electrostatic discharge were determined for NC and a 50:50 blend of NC/compost mixture at 0% and 30% moisture. The data is provided for use in determining operating conditions and associated risks for conducting follow–on composting studies.

14. SUBJECT TERMS Nitrocellulose, NC, NC fines, Compost, Reactivity, Sensitivity, Flame, Shock, Deflagration to Detonation Test (DDT), Critical Diameter (C_d), Moisture.

15. NUMBER OF PAGES 74

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

CONTENTS

CONTENTS (con't)

S.0 EXECUTIVE SUMMARY

S.1 Objective

The primary objective of this study was to investigate and define the reactivity of Nitrocellulose (NC) and NC/compost mixtures to flame and shock stimuli as functions of NC and moisture content. Also, initiation sensitivity to impact, friction, and electrostatic discharge energies were determined for NC, and a selected NC/compost mixture.

S.2 Summary and Conclusions

This study established the maximum NC and minimum moisture requirements for controlling explosive reactivity to flame and shock stimuli for the compost mixtures tested. These limits are valid for dispersed wet NC fines or fibers when combined with compost mixtures in confinements no greater than those used during the flame and shock reactivity tests presented in this study. Dry NC presents a real fire and explosion hazard to personnel. A hazards study to assess risk to personnel and/or equipment is recommended prior to full-scale NC fines composting.

Flame reactivity tests determined that <u>dry</u> NC/compost mixtures containing less than 12% NC do not react explosively in the Bureau of Mines (BOM) Deflagration to Detonation (DDT) test. Standard Critical Diameter (C_d) for explosive shock propagation tests determined that <u>dry</u> NC/compost mixtures containing less than 10% NC do not propagate an induced explosive reaction in ≤ 2.5" diameter, schedule 40 steel pipe. The addition of water to the NC/compost mixtures further reduces sensitivity to flame and shock, and precludes explosive reactions for mixtures with NC content up to 45% in the DDT and C_d tests.

A summary of the flame and shock reactivity test results is shown graphically in Figure 1. The reactivity of NC/compost mixtures to flame and shock stimuli is comparable at NC levels up to 37%. Above the 37% NC level, NC/compost compositions require more moisture to prevent reactivity to flame stimuli (DDT test) than required to prevent propagation of an explosive reaction in the C_d test. NC alone requires a minimum of 55% moisture to maintain non-reactivity to flame in the DDT test.

Laboratory analyses of NC/compost blends determined that moisture variability within blends averaged 3.1%, indicating good moisture distribution. Laboratory analyses for NC content was more variable at ±6% from the weighed quantities added to the mixer. It is likely that the NC variability was related to difficulty in obtaining small, representative samples from the heterogeneous NC/compost mixture. The analytical data indicates good dispersion of NC and water into the compost.

Impact, friction, and electrostatic discharge (ESD) tests were performed on NC individually and as a 50:50 blend of NC/compost mixture at 0% and 30% moisture levels. As expected, the data shows the ease of initiation (less energy required) of dry NC versus 30% water–wet NC. The data was statistically analyzed to provide plots of probability of initiation versus energy stimulus at the 95% confidence level. This data can be used in future hazards studies to quantitatively assess the risk of NC initiation by mechanical equipment during composting operations.

1.0 INTRODUCTION

Manufacture of NC for use in propellants and explosives has resulted in NC fines discharges from the manufacturing process. Process waters from nitrocellulose (NC) purification and stabilization operations contain NC fines. Typically these fines have been collected in settling basins and recycled into the process. Some fines however have settled in lagoons in the waste water treatment systems. The NC fines from Radford waste waters have varying degrees of nitration which can range from 12.4% to 13.05%.

The United States Army Environmental Center (USAEC) is evaluating composting as a method for disposing of NC fines which cannot be recovered or recycled. Previous exploratory composting studies with <2% NC contaminated soil resulted in NC degradation.[1] Limited, small–scale tests with NC concentrations up to 60% were also effective in achieving NC degradation.

Under USAEC contract, this reactivity testing program was initiated to investigate and define the explosive reactivity of various NC/compost mixtures, as functions of NC and moisture content, to flame and shock stimuli. Roy F. Weston, Inc., under separate contract to USAEC, selected the compost amendments and determined three amend recipes (Table 1) to meet appropriate biological composting criteria. The amendments (cow manure, horse manure, straw, sawdust) were milled, dried, bagged and supplied to Radford Army Ammunition Plant for use with Radford manufactured NC. A detailed test plan[2] was prepared and implemented to safely attain the objectives of this study. The key plan feature was development of a reliable method to prepare small–scale (3 to 10 pound) homogeneous blends of NC/compost for subsequent testing.

This report documents the findings and study conclusions resulting from the flame and shock reactivity testing of NC and selected NC/compost compositions at various NC and moisture levels.

2.0 EXPERIMENTAL TEST PLAN/APPROACH

A basic explanation and pertinent details of the approach used in this study is provided in the following; descriptions of specific tests are provided in Appendices D, E and F.

2.1 Overall

The test scheme is shown in Figure 2. Initially, reviews were conducted to confirm the compost materials as non–toxic and compatible with NC. This was followed by development of a test sample preparation method to provide repeatable disbursement of the NC, compost amendments and moisture. Homogeneity of the NC/compost mixture blends was determined by laboratory analysis. An exploratory series of screening tests were performed to determine the most reactive NC/compost mixture to be used in the shock (C_d) and flame (DDT) tests. Then the other amendment mixtures were tested to validate their flame and shock reactivity against these results. Based on its physical content and shock reactivity characteristics, the initiation sensitivity of one NC/compost mixture to impact, friction, and electrostatic spark stimuli was determined for comparison with NC at 0% and 30% moisture levels.

2.2 Nitrocellulose Selection

Nitration level influences the explosive reactivity of NC. Experiments by others[3] determined that an increase in nitrogen content increases the heat of explosion and NC inflammability. Army Technical Manual TM 9–1300–214 states that the brisance of NC as determined using "the sand test" increases as the nitrogen content increases.[4] NC containing a uniformly high nitration level of 13.15% was used during this study to assure that the results represent worst case conditions that may be encountered during NC composting operations.

NC wastewater "fines" are NC fibers of varying lengths washed from the NC product during processing. The "fines" are generally shorter in length than the NC product used to make propellants. Fiber length could have an effect upon the density of NC packed into test containers and the compost pile. Tests by others[5] indicate that a higher degree of fineness reduces the inflammability of NC by increasing its loading density under a given pressure. However, with proper mixing of the NC fines into the compost, little packing is expected and the inflammability of NC fines should be comparable to the stabilized NC used during the flame and shock reactivity tests.

NC wastewater fines contain varying degrees of stabilization (retain some level of nitrating acids). Partially stabilized NC will decompose at a faster rate over time

than stabilized NC.[6] Decomposition of NC at ambient or composting temperatures and in a well ventilated pile is only likely to result in some additional pile heating and evolution of decomposition gases. If the NC self heats to the autoignition temperature, NC ignition will occur. While accelerated decomposition of partially stabilized NC is a safety concern during composting operations, the reaction that will occur after ignition of partially nitrated NC should be no greater than that of stabilized NC. This study was conducted using stabilized NC.

2.3 Amendment Toxicity/Compatibility

Inspection of the amendment composition analysis data furnished by Roy F. Weston Inc., (Appendix A) determined the primarily organic materials (straw, sawdust, and manures) to be of incidental personnel exposure hazard. The use of dust masks and gloves were incorporated into the handling procedures where needed.

The RAAP standard modified Taliani test[7] was used to verify that compost amendments were chemically compatible with NC (Appendix A). The modified Taliani test measures the rate and magnitude of decomposition gases released when incompatible materials react chemically in a closed inert atmosphere for 23 hours at 200°F.

2.4 Sample Preparation

NC and compost amendments were combined into "blends" using known weights of individual ingredients.[8] The NC, manures, straw, and sawdust were weighed within 1 ounce. Regular determination of moisture level in the stored ingredients was used to calculate the ingredient addition weights and provide the desired NC/compost ratio (dry weight basis) for each blend. The required moisture addition for each blend was calculated, weighed within 1/8 ounce, and combined with the NC/compost mixture(s) in a 3.5 cubic foot plastic lined cement mixer (Appendix B). A limited number of blends were open air dried to produce blends with moisture levels below that of the stored ingredients. The blends thus provided multiple test samples with the desired NC:compost mixture ratio and common moisture content.

A typical blend weighed approximately 6 pounds. Each was assigned a three digit identification number and maintained in sealed plastic bag(s) until tested. To reduce biological activity, blends were stored in layers less than 2" thick on a flat surface in a temperature conditioned (70–75°F) environment. Blends were tested within three days of preparation. Residues, if any, were disposed of by open burning in accordance with established procedures at RAAP.

2.5 Laboratory Analysis

Moisture content of any analyzed sample was determined by loss in weight technique. Multiple samples were used to verify moisture distribution throughout the prepared blend. Additional samples were taken at test container loading to assure the moisture level of the particular trial being performed. The container loading moisture levels were used in analysis and plotting of the reactivity data.

The NC content of the NC/compost mixtures was analyzed using the procedures provided in Appendix C. A procedure change was initiated after blend 004 due to the presence of pea size clumps of NC in the sample. Where this size of NC appears well dispersed in a 6 pound blend, it becomes a significant portion of a 5 gram sample, which can give erratic analysis results. Therefore the analyzed sample size was doubled to 10 gram and the analysis technique modified in an attempt to reduce variability. The as–weighed constituent percentages were used in analysis and plotting of the reactivity data.

2.6 Reactivity Screening

The objective of the exploratory screening tests was to determine which one of the NC/compost amendment mixtures listed in Table 1 was more reactive to flame or shock stimuli than the others. The compost amendment mixtures were combined with NC in the same percentages and moisture content, then subjected to flame in the DDT test (Appendix E). A standard DDT test container was instrumented with a pressure transducer to record reaction pressures inside the closed schedule 80 steel pipe. The pressure rate–of–rise, and peak pressure were used to indicate the magnitude of the reaction inside the closed chamber. The amendment mixture determined to be most reactive became the workhorse mixture for subsequent C_d and DDT test series.

2.7 Critical Diameter

The objective of the critical diameter test was to establish the smallest diameter for propagating explosive reactions for NC and NC:compost mixture ratios, at various moisture levels. The C_d test was chosen in lieu of the BOM Zero Gap test because the Zero Gap test only provides go no–go test results in a 1.43 inch diameter pipe. If the 1.43 inch diameter is below the critical diameter for the explosive being tested, then it would result in a false (negative) result. The C_d test was chosen as a better indicator of explosive reactivity to shock stimuli.

A donor charge of Composition C–4 was used to induce detonation of the acceptor test sample confined in various diameters of schedule 40 steel pipe. The donor charge size is increased as the acceptor diameter is increased. The prepared blends of NC/compost were loaded into the test pipes and the donor charges remotely

detonated. The subsequent test sample reaction was defined as positive or failure for explosive propagation based on analysis of container fragmentation (Appendix D)

2.8 Deflagration to Detonation Transition

DDT tests were performed to determine the susceptibility of NC and varying NC:compost mixture ratios and moisture contents to transit from burning to an explosion. The NC/compost blends were loaded into the test pipes and remotely tested. A RDX igniter subjected the material to a strong flame stimulus. An explosion reaction is indicated if the steel pipe or one of the end caps is fragmented into at least two distinct pieces (see Appendix E).

2.9 Hot Wire Ignition

The experimental ignition tests were performed to investigate if specific NC/compost mixtures, which exhibited positive reactions in the DDT test, would support open burning in an unconfined state. Eight ounce piles of NC/compost mixtures were placed, semi–confined (under a 7.5 pound weight) and unconfined, on a metal pan and remotely ignited by a hot wire. The material was observed by video for its ability to sustain burning after ignition.

2.10 Initiation Sensitivity

Impact, friction, and electrostatic discharge initiation tests were conducted to determine the threshold initiation level (Til) of NC and a selected NC/compost mixture at 0% and 30% moisture levels. Sufficient tests were performed at energy levels above the Til to provide data for statistical determination of the initiation probability at a 95% confidence level. These data can be used to quantitatively assess the probability of NC and NC/compost mixture ignition. Further explanation of each test is provided in Appendix F.

3.0 DISCUSSION OF RESULTS

3.1 Sample Uniformity

As shown in Table 2, the range of individual samples from each blend analyzed for moisture content collectively averaged 3.1%. No correlation or pattern can be seen to relate moisture variability to the NC level or specific compost mixture. The ability to achieve targeted moisture levels during blend preparation was found to be directly related to the current moisture of the amendments and thus required frequent monitoring. Flame and shock reactivity of the test samples was reported based on the actual rather than the target moisture level.

Analysis of test samples for NC content show an average sample range of 10.2% with an average variance of 6% from the targeted 25, 50 or 75% content levels. This variability occurred in all NC/compost mixture combinations and moisture levels. Sample variability is likely to have been caused by one or more of the following:

(1) The presence or absence of NC lumps in the laboratory analyzed samples offers the most likely explanation of NC content variability. Examples of the pea size lumps can be seen in two NC samples shown in Figures 3a and 3b. Their presence was also noted in NC/compost mixture blends at all moisture levels as shown in Figures 3c through 3e. This observation prompted an change in analytical technique. The analyte size was increased from 5 grams to 10 grams. The revised analysis technique (Appendix C) was instituted after blend 004.

The use of additional size reduction (grinding) of the samples taken from the blend, prior to selection of the 10 gram sample for analysis of NC content, is recommended to reduce the effect of NC lumps on analytical results.

(2) Weighing variability during sample blend preparation could explain some of the variance from target NC levels. NC samples were weighed to ±1 ounce,which corresponds to NC composition variability of up to 4%, 2% and 1% for the 25%, 50% and 75% NC blends respectively.

3.2 Reactivity Screening

The purpose of this investigative phase was to test and rank each compost mixture listed in Table 1 for explosive reactivity and severity when tested in combination with NC. Reactivity screening tests determined that compost amendment mixture #3 generated the highest reaction pressure in an instrumented closed pipe DDT test. It was deemed most reactive of the three compost mixtures and selected as the amendment mixture to be used in subsequent explosive reactivity tests.

Thirty percent water–wet 50:50 NC:amendment mixtures were prepared and tested using standard BOM DDT test protocols (three trials each, Appendix E). Instrumentation recorded test container internal pressure for two of the three trials per blend. Results of the screening tests are shown in Table 3. Rate of pressurization (psi/sec) data exhibited a trend with peak pressure but was individually non–conclusive. Average peak reaction pressure (psi) was the discriminator used to rank reactivity. Based on these tests, the most reactive was NC/compost mixture #3, and the least reactive was NC/compost mixture #2.

A probable explanation of the higher reaction pressures obtained with mixture #3 is the interaction of the higher level of combustibles (straw and sawdust) in this mixture with the strong flame stimulus used in the DDT test. Mixture #3 was used for the majority of the reactivity testing program in an attempt to reduce the total number of trials required. Mixtures #1 and #2 were then used in subsequent flame and shock reactivity verification tests.

3.3 Critical Diameter

The C_d at which a NC/compost mixture will sustain a propagating shock induced explosive reaction varies with both NC content and percent moisture. Increasingly larger diameters are required to propagate an explosion in NC or NC/compost mixtures as the water content is increased or the NC percentage is lowered.

The 2 1/2 inch diameter test level was chosen as an upper limit due to the considerable energy released by detonation of the 2.3 pound Composition C-4 donor charge. Shock stimuli of this magnitude exceeds a reasonable shock stimuli expected to occur in NC processing operations.

The C_d data for NC, individually and in mixture combinations with the three compost amendments, is shown graphically as a function of moisture content in Figure 4 and summarized in Table 4. A description of the C_d Test is available in Appendix D with examples of failure and positive test results shown in Figure 5.

As expected, NC alone is more reactive than any of the tested NC/compost amendment mixtures. Figure 4 shows the effect of sample moisture on the C_d curve for NC. The C_d is 1/2" at 30% moisture and increases to 2 1/2" at ≈39% moisture. When subjected to a shock stimulus, NC will propagate an explosive reaction in diameters above and at moistures below those shown.

Testing of compost mixture #3 at varying NC contents and moisture levels determined the C_d curves shown in Figure 4. In comparison with NC, the substitution of mixture #3 into the test sample in 25% increments resulted in decreased shock sensitivity at all moisture levels. The C_d for a 75% NC blend is two to three test levels larger than NC for the same moisture content. Further, compost mixture #3 shows a unique offset curve at the intermediate (1 to 2 inch) test sizes in a 75% NC blend.

Testing of compost mixtures #1 and #2 for verification against the reactivity of mixture #3 generated their individual C_d curves (Figure 4). In a 50% NC blend, a marginal increase in moisture dependence (5% more moisture required) was found for compost mixture #2 to attain a 2 1/2 inch C_d. In a 25% NC blend, all three compost mixtures exhibit C_d's above the upper test level of 2 1/2 inch at moistures <13%.

The test sample bulk densities (Table 4) exhibit the expected trend of increased density with increased moisture content. However inconsistencies exist as in the 75:25 ratio lowest moisture tests for mixtures #1 and #2. These tests resulted in C_d's <1/2 inch. The increased densities are a probable explanation of the steep slope of these mixture's C_d curves in comparison with mixture #3 at this ratio. The dense sample transmits the induced shock more readily and can result in a lower C_d at the same moisture level. This phenomena has been observed in previous testing of other explosive materials.[9] Further attempts at verification were not performed during this study.

The propagating velocities for these tests were determined from time–position traces recorded during the critical diameter tests and are reported in Table 4. All traces exhibited velocity decrease through the pipe length, indicative of a decaying reaction.

3.4 Deflagration to Detonation Transition

Flame reactivity testing determined that the propensity of the NC/compost mixtures to transit from burning to an explosive reaction varies with both NC content and moisture content. Decrease in moisture level is required to sustain the explosive reaction as the NC content is reduced. A description of the DDT test is available in Appendix E with examples of positive and failure test results shown in Figure 7.

For NC and each NC/compost ratio tested, the reactive region was determined within 5% moisture content of the non–reactive region. The explosive reactivity results are presented graphically in Figure 6 and the data summarized in Table 5. As shown in Figure 6, NC alone requires >55% moisture to be non–reactive in the DDT test. The non–reactive limits for compost mixtures containing 75%, 50% and 25% NC levels (dry weight basis) were determined to be at >44%, >26% and >9% moisture, respectively. NC/compost mixture non–reactivity at zero moisture is projected from this data trend to be ≤12% NC. Limited testing was performed at moistures <15% due to the risk of handling initiation sensitive dry NC.

Consistent with the screening test determination, mixture #3 required a higher moisture content to remain non–explosive as compared to the other mixtures. This was verified with selective testing of mixtures #1 and #2 at the 75 and 50% NC content. Therefore mixture #3 data was also used to establish the non–reactive region at <25% NC content where testing was limited due to safety concerns.

As shown in Table 5, the sample density increased with increasing moisture content across all compost mixtures. The NC densities were somewhat higher than the compost mixtures, however this is expected since the NC was tested at higher moisture levels.

An observation worthy of note from the DDT testing was the change in magnitude of the container damage as reactive compositions were approached. As the sample moisture was decreased, the container damage changed from none, to ejection of one or both pipe container end caps, to splitting of the pipe wall. Basically, the reaction became more violent as the moisture was reduced until the DDT positive reactivity criteria was met.

3.5 Hot Wire Ignition

Limited testing determined NC/compost mixtures would not sustain burning at moisture levels ≥30% in semi–confined and unconfined trials (Table 6). Confinement was produced by placing a steel weight on the sample pile after

submerging the ignition wire. The hot wire was placed on the sample in the unconfined tests. Compost mixture #3, determined most reactive to flame stimulus in the screening test, was used predominately. Neither a 75% NC content at 29% moisture, or a 50% NC content at 23% moisture sample would continue burning after a hot wire ignition source was removed. In comparison, both samples exhibited positive reactions to flame stimuli in confinement in the DDT test. Reaction differences are attributed to increased burning rate of NC with pressure in the confined DDT test.

Data is summarized in Table 6 with documentation (before and after photos) of unconfined and semi-confined test results shown in Figure 8.

3.6 Initiation Sensitivity

Initiation sensitivity to impact, friction, and electrostatic discharge stimuli were determined for NC, and 50:50 NC/compost mixture #2, at 0% and 30% moisture levels. Mixture #2 was selected for these tests instead of the more flame reactive mixture #3 for two reasons; its greater shock reactivity in a 50:50 ratio for similar moisture levels (see Critical Diameter results section) and the higher grit content from the horse manure component. Typically, the presence of grit increases a material's impact and friction initiation sensitivity due to the increased energy per unit of surface area.[10] The 50:50 NC/compost mixture contains as much NC as the anticipated upper limit of NC to be used in composting studies. The 0% moisture level is an obvious worst case condition for sensitivity (and reactivity) while the 30% moisture level was determined non-reactive to both flame and shock stimuli during these tests. Additionally, 30% moisture is slightly below the reported typical range for conventional composting.[11]

Threshold initiation level (TIL) was determined for impact, friction, and ESD mechanisms on each mixture and is presented in Tables 7 and 8. For each of the initiating stimuli, the data shows the ease of initiation (less energy required) of dry NC versus 30% water-wet NC. As expected, comparison of the data shows NC to be more sensitive than the NC/compost mixture at the same moisture levels. Further, the dry NC/compost mixture is more sensitive than the 30% wet NC, reflecting the acute sensitivity of the dry NC constituent.

The data were statistically analyzed to provide plots of probability of initiation versus energy stimulus at the 95% confidence level and are presented in Figures 9 and 10. This data can be used in future hazards studies to assess the risk of NC initiation in composting operations.

4.0 INTERPRETATION OF RESULTS

The data generated by this study has direct application to full–scale composting operations. If the compost composition is maintained in the non–reactive region shown in Figure 1 , then the NC/compost composition can be expected to be non–reactive to flame and shock stimuli. The shock (C_d) and flame (DDT) tests purposely subjected the NC/compost samples to energies and confinements greater than what is expected to occur in normal compost pile operations. Therefore NC/compost mixtures designated non–reactive are not expected to transit from burning to an explosive reaction should initiation occur.

In summary, the maximum NC content for safe use in the tested compost mixtures can be extracted from the trimodal, reactivity summary plot (Figure 1) at the intersection of the non–reactive region border with the minimum moisture level maintained in the mixture.

5.0 WARRANTY AND DISCLAIMER

Within the scope of work, Alliant warrants that it has exercised its best efforts in performing the hazards analysis and testing reported herein, but specifically disclaims any warranty, expressed or implied, that hazards or accidents will be completely eliminated or that any particular standard or criterion of hazard or accident elimination has been achieved if the findings and recommendations of Alliant Techsystems are adopted.

6.0 REFERENCES

1. Roy F. Weston, Inc., "Field Demonstration–Composting of Propellants Contaminated Sediments at the Badger Army Ammunition Plant (BAAP)," Roy F. Weston, Inc., West Chester, Pennsylvania, Report Number CETHA–TE–CR–89061, March 1989.

2. C. A. Elsea, "Program Test Plan," Hercules Incorporated, Radford Army Ammunition Plant, Report Number HG–93–M–044, Rev. 1, March 30,1994.

3. Urbanski, T., "Chemistry and Technology of Explosives," Pergamon Press, New York, 1985, Volume 2, pp 314, 316, 407.

4. Department of the Army Technical Manual, "Military Explosives," TM 9–1300–214, September 1984.

5. Urbanski, T., op. cit., p 316.

6. Urbanski, T., op. cit., pp 307,308

7. Alliant Techsystems, "Automated Taliani," Radford Army Ammunition Plant, UOP 4–18–33A, Rev. 1, April 19, 1993.

8. Alliant Techsystems, "Blending of Water–wet Nitrocellulose and Organic Compost Mixtures," Radford Army Ammunition Plant, GOP 4–29–145 Rev. 0, May 17, 1994.

9. T. W. Ewing, "Explosive Contaminated Soil Reactivity to Flame and Shock Stimuli as a Function of Composition," Hercules Aerospace Company, Radford Army Ammunition Plant, Report Number HA–86–R–8, August, 1986.

10. Alliant Techsystems, "HERC Engineering Analysis Manual," Allegany Ballistics Laboratory, Cumberland, Maryland, Edition I, December, 1973.

11. Roy F. Weston, Inc., "Composting of Nitrocellulose Fines–Hazards Analysis," Draft Test Plan, Prepared for USAEC, Contract DACA31–91–D–0079, Task Order 0007, January 1994.

Table 1 Composition of Compost Mixtures[a]

Compost Mixture Number	Amendment Content (% dry weight basis)			
	Cow Manure	Horse Manure	Saw Dust	Straw
0[b]	---	---	---	---
1	47	---	---	53
2	---	45	---	55
3	2	---	65	33

a Compost mixture recipes #1, #2 and #3, and compost amendments furnished by Roy F. Weston, Inc.

b Mixture number "0" assigned to 100% nitrocellulose.

--- Amendment not used in this mixture.

Table 2 Laboratory Analyses of NC/Compost Mixture Blends

Blend Number	Compost Mixture Number	Moisture (%)			Nitrocellulose (%)[a]		
		Blend Target	Sample Analysis[b]		Blend Target	Sample Analysis[c]	
			Range	Average		Range[d]	Average[d]
001	1	30	30.3 – 32.1	30.7	50	45 – 48	46
002	2	30	31.0 – 32.5	31.9	50	44 – 58	51
003	3	30	30.3 – 32.7	31.5	50	51 – 68	58
004	3	20	21.2 – 25.0	22.8	50	39 – 68	55
005	3	30	27.6 – 30.1	28.8	75	85 –115	98
006	0	40	34.1 – 39.1	36.7	100	NT	NT
007	3	20	22.0 – 24.4	23.3	75	83 – 87	85
008	3	40	37.0 – 40.8	39.6	75	NA	92
009	0	50	44.8 – 56.4	49.8	100	NT	NT
010	3	50	48.8 – 51.2	50.6	75	NA	87
011	0	30	26.3 – 31.8	28.9	100	NT	NT
012	0	54	52.4 – 54.8	53.6	100	NT	NT
013	0	60	58.5 – 60.0	59.2	100	NT	NT
014	3	27	23.6 – 29.8	26.0	50	37 – 42	40
015	3	45	36.9 – 39.1	38.2	75	78 – 85	81
016	3	10	16.0 – 20.5	17.5	25	35 – 46	41
017	2	30	28.4 – 32.7	30.0	75	75 – 95	83
018	1	20	21.1 – 24.1	22.4	75	77 – 86	82
019	1	20	17.8 – 20.8	19.6	50	50 – 55	52
020	3	20	20.2 – 22.9	21.8	50	53 – 69	60
021	3	45	40.8 – 44.3	41.6	75	59 – 71	66
022	0	55	56.2 – 53.4	55.4	100	NT	NT
023	2	23	19.8 – 23.1	21.6	50	44 – 52	49
024	0	20	19.5 – 20.0	19.7	100	NT	NT
025	1	40	34.1 – 39.8	35.8	75	69 – 76	73
026	2	40	32.3 – 40.0	35.7	75	80 – 85	83

a Dry weight basis.
b Loss in weight determination, three to five samples taken after blend preparation concurrent with samples for NC composition analysis.
c Using up to three samples per blend, determined by acetone extraction, dried, weighed. See Appendix A for detailed procedures. Technique change after blend 004.
d NA – not applicable for single samples. NT – 100% NC not tested.

Table 2 Laboratory Analyses of NC/Compost Mixture Blends (con't)

Blend Number	Compost Mixture Number	Moisture (%) Blend Target	Moisture Sample Analysis[b] Range	Moisture Sample Analysis[b] Average	Nitrocellulose (%)[a] Blend Target	Nitrocellulose Sample Analysis[c] Range[d]	Nitrocellulose Sample Analysis[c] Average[d]
027	1	23	22.0 – 27.8	23.6	50	49 – 58	52
028	2	23	22.3 – 23.1	22.5	75	74 – 80	78
029	2	20	19.2 – 19.7	19.5	50	45 – 76	57
030	1	30	27.6 – 28.3	27.9	75	75 – 83	79
031	1	40	37.0 – 39.0	38.0	75	77 – 80	78
032	2	20	18.8 – 20.4	19.4	25	17 – 44	26
033	3	10	9.1 – 9.5	9.3	25	20 – 27	23
034	2	10	9.2 – 12.5	10.6	25	18 – 23	20
035	1	10	10.0 – 16.7	12.6	25	25 – 28	27
036	1	25	23.2 – 26.7	24.2	50	46 – 52	49
037	2	45	39.8 – 44.2	41.5	75	80 – 82	81
038	3	10	24.6 – 28.6	26.7	75	74 – 91	83
039	1	10	5.2 – 7.6	6.4	50	53 – 59	56
040	2	10	11.6 – 11.8	11.7	50	50 – 53	52
041	3	10	4.1 – 5.5	4.8	50	41 – 47	44
042	2	25	24.8 – 28.6	26.6	50	55 – 58	56
043	3	18	17.5 – 18.3	17.9	75	NA	78
044	3	35	30.7 – 33.4	32.1	75	74 – 76	75
045	0	25	23.1 – 23.6	23.4	100	NT	NT
046	2	30	29.1 – 30.1	29.9	50	NA	57
047	2	0	0.6 – 1.9	1.2	50	NA	49
		Average Range:	3.1		Avg. Range:	10	
						Average Variance From Target: 6	

a Dry weight basis.

b Loss in weight determination, three to five samples taken after blend preparation concurrent with samples for NC composition analysis.

c Using up to three samples per blend, determined by acetone extraction, dried, weighed. See Appendix A for detailed procedures. Technique change after blend 004.

d NA – not applicable for single samples. NT – 100% NC not tested.

Table 3 Results of NC/Compost Mixtures Screening for Explosive Reactivity (50:50 NC/Compost at 30% Moisture)

Test Sample			Test Results			
Mixture No. and Composition[a]	Ambient Temp.[b] (°F)	Density (gm/cc)	Sample Consumed (%)	Peak Pressure (psi)	Rate of Rise (psi/sec)	Reactive for DDT[c] Criteria
Mixture #1 47% COWM 53% STRAW (Blend No. 001)	82	0.11	100	--	--	failure
	82	0.28	100	11,680	556	failure
	82	0.31	100	12,400	445	failure
	52	0.30	100	--	--	failure
			Average Peak:	12,040		
Mixture #2 45% HORM 55% STRAW (Blend No. 002)	75	0.38	100	13,120	468	failure
	75	0.30	90	9,440	291	failure
	52	0.29	95	--	--	failure
			Average Peak:	11,280		
Mixture #3 2% COWM 65% SAWD 33% STRAW (Blend No. 003)	52	0.30	100	12,800	528	failure
	52	0.31	100	13,520	676	failure
	52	0.32	95	--	--	failure
			Average Peak:	13,080		

a COWM = Cow manure, HORM = Horse manure, SAWD = Saw dust, STRW = Straw; all shown as dry weight basis percentages.

b Ambient air temperature during test. All NC/Compost mixtures were taken from 70°F storage, loaded into ambient temperature test pipe, and tested within 30 minutes.

c For a positive reaction in the Deflagration to Detonation Test (DDT), either the pipe or one of the end caps must be fragmented into at least two distinct pieces.

-- Data not recorded for this trial.

Table 4 Critical Diameter For Explosive Propagation For Nitrocellulose/Compost Mixture Blends

NC (%)[a]	Compost (%)[a]	Test Size (in)	Propagating Velocity (m/s)	Number Trials positive–failure[b]	Moisture (%)[c]		Bulk Density (gm/cc)[d]		Blend No.
			Range		Range	Avg.	Range	Avg.	
COMPOST MIXTURE #0 Dry Weight Composition: 100% Nitrocellulose									
100	0	<0.5*	2999	1–0	19.5–20.0	19.7	NA	0.64	024
		<0.5*	3495	1–0	23.1–23.6	23.4	NA	0.69	045
		≥0.5–<1.0*	504–1611	0–3	26.3–31.9	28.9	0.28–0.55	0.44	011
		1.0	891–2459	1–2			0.39–0.46	0.42	
		1.5	2291	1–0			NA	0.47	
		1.5	831	0–1	34.1–39.1	36.7	NA	0.43	006
		≥2.0–<2.5*	275–738	0–3			0.46–0.50	0.49	
		2.5	1911	1–0			NA	0.66	
		>2.5	485–935	0–3	44.8–56.4	49.8	0.82–0.88	0.84	009
COMPOST MIXTURE #1 Dry Weight Composition of Compost: 47% Cow Manure, 53% Straw									
25	75	>2.5*	1312–1701	0–3	10.0–12.6	12.6	0.30–0.34	0.31	035
50	50	≥0.5–<1.0*	1701–1701	0–3	5.2–7.6	6.4	0.32–0.50	0.40	039
		1.0	1826	1–0			NA	0.22	
		2.0	NR	0–1	17.8–20.8	19.6	NA	0.38	019
		>2.5*	1164–1470	0–3			0.38–0.45	0.40	

a Dry weight basis.
b Reaction defined by container damage, pipe must split full 24" length for positive reaction.
c Samples taken during container loading.
d Average if multiple trials performed per test size.
* Indicates C_d for this NC/Compost mixture ratio and moisture level. C_d defined as test diameter with no positive reactions and at least one positive reaction at next larger test diameter.
NR Data not recorded.
NA Range not applicable to single trial.

Table 4 Critical Diameter For Explosive Propagation For Nitrocellulose/Compost Mixtures (con't)

NC (%)[a]	Compost (%)[a]	Test Size (in)	Propagating Velocity (m/s)	Number Trials positive–failure[b]	Moisture (%)[c]		Bulk Density (gm/cc)[d]		Blend No.
			Range		Range	Avg.	Range	Avg.	
COMPOST MIXTURE #1 (con't) Dry Weight Composition of Compost: 47% Cow Manure, 53% Straw									
75	25	<0.5*	2175	1–0	21.1–24.1	22.4	NA	0.60	018
		1.0	2252	1–0			NA	0.31	
		1.5	2593	1–0			NA	0.39	
		1.0	563	0–1	27.6–28.3	27.9	NA	0.47	030
		≥1.5–<2.0*	979–1416	0–3			0.41–0.45	0.43	
		2.0	2593	1–0			NA	0.48	
COMPOST MIXTURE #2 Dry Weight Composition of Compost: 45% Horse Manure, 55% Straw									
25	75	>2.5*	1470–1701	0–3	9.2–12.5	10.9	0.29–0.31	0.30	034
		>2.5*	1117–1470	0–3	18.8–20.4	19.4	0.35–0.35	0.35	032
50	50	≥0.5–<1.0*	1582–1701	0–3	7.4–8.3	7.4	0.34–0.46	0.40	040
		1.0	1958	1–0				0.35	
		≥1.5–<2.0*	602–682	0–3	19.2–19.7	19.5	0.34–0.45	0.39	029
		2.0	1416	1–0				0.34	
		2.5	1237	1–0				0.42	
		1.0	1070	0–1	24.8–28.6	26.6	NA	0.30	042
		1.5	806	0–1			NA	0.35	
		2.0	891	0–1	24.8–28.6	26.6	NA	0.35	042
		>2.5*	1364–1701	0–3			0.37–0.39	0.38	

a Dry weight basis.
b Reaction defined by container damage, pipe must split full 24" length for positive reaction.
c Samples taken during container loading.
d Average if multiple trials performed per test size.
* Indicates C_d for this NC/Compost mixture ratio and moisture level. C_d defined as test diameter with no positive reactions and at least one positive reaction at next larger test diameter.
NR Data not recorded.
NA Range not applicable to single trial.

Table 4 Critical Diameter For Explosive Propagation For Nitrocellulose/Compost Mixtures (con't)

NC (%)[a]	Compost (%)[a]	Test Size (in)	Propagating Velocity (m/s) Range	Number Trials positive–failure[b]	Moisture (%)[c] Range	Moisture (%)[c] Avg.	Bulk Density (gm/cc)[d] Range	Bulk Density (gm/cc)[d] Avg.	Blend No.
COMPOST MIXTURE #2 (con't) Dry Weight Composition of Compost: 45% Horse Manure, 55% Straw									
75	25	<0.5*	2100	1–0	22.2–23.1	22.5	NA	1.4	028
		1.5	1312	0–1	28.4–32.7	30.1	NA	0.47	017
		2.0	682	0–1			NA	0.44	
		>2.5*	510–1261	0–3			0.50–0.51	0.51	
COMPOST MIXTURE #3 Dry Weight Composition of Compost: 2% Cow Manure, 65% Saw Dust, 33% Straw									
25	75	>2.5*	2252–2787	0–3	13.7–17.5	16.1	0.28–0.29	0.28	033
50	50	<0.5*	1762–2028	2–1	4.8–5.5	4.7	0.46–0.55	0.50	041
		>2.5*	1117–1826	0–3	20.2–22.9	21.8	0.44–0.48	0.45	020
		1.5	NR	0–1	21.2–25.0	22.8	NA	0.37	004
		2.0	NR	0–1			NA	0.25	
75	25	<0.5*	3234	1–0	6.2–6.5	6.4	NA	0.37	038
		<0.5*	2687	1–0	17.5–18.3	17.9	NA	0.64	043
		≥1.0–<1.5*	831–1505	0–3	22.0–24.3	23.3	0.23–0.32	0.28	007
		1.5	2121	1–0			NA	0.31	
		≥1.5–<2.0*	738–926	0–3	27.6–30.1	28.8	0.28–0.32	0.31	005
		2.0	NR	1–0			NA	0.32	
		2.0	806	0–1	30.7–33.4	32.1	NA	0.47	044
		>2.5*	563–848	0–3			0.56–0.57	0.57	
		>2.5*	869–979	0–3	37.0–42.1	39.6	0.59–0.59	0.59	008

a Dry weight basis.
b Reaction defined by container damage, pipe must split full 24" length for positive reaction.
c Samples taken during container loading.
d Average if multiple trials performed per test size.
* Indicates C_d for this NC/Compost mixture ratio and moisture level. C_d defined as test diameter with no positive reactions and at least one positive reaction at next larger test diameter.
NR Data not recorded.
NA Range not applicable to single trial.

Table 5 Explosive Reactivity of Nitrocellulose/Compost Mixture Blends Determined By Deflagration to Detonation Test

NC (%)[a]	Compost (%)[a]	Sample Reactive[b] yes/no	Test Reactions positive –negative[c]	Moisture (%)[d]		Bulk Density (gm/cc)[e]		Blend No.[f]
				Range	Avg.	Range	Avg.	
COMPOST MIXTURE #0 Dry Weight Composition: 100% Nitrocellulose								
100	0	yes	1–0	44.8–56.4	49.8	NA	0.69	009
		yes	1–2	52.4–54.8	53.6	0.67–0.68	0.68	012
		* no	0–3	53.4–56.2	55.4	0.66–0.69	0.67	022
		no	0–3	58.5–60.0	59.2	0.75–0.86	0.82	013
COMPOST MIXTURE #1 Dry Weight Composition of Compost: 47% Cow Manure, 53% Straw								
25	75	no	0–3	17.4–23.1	19.4	0.25–0.28	0.27	035
50	50	yes	1–2	22.0–27.8	23.6	0.33–0.37	0.35	027
		* no	0–3	23.2–26.7	24.2	0.31–0.34	0.33	036
		no	0–3	30.3–32.1	30.7	0.11–0.31	0.23	001
75	25	no	0–3	39.1–41.3	40.0	0.45–0.45	0.45	025
COMPOST MIXTURE #2 Dry Weight Composition of Compost: 45% Horse Manure, 55% Straw								
25	75	no	0–3	10.6–11.1	11.0	0.23–0.24	0.24	034
50	50	no	0–3	22.4–24.6	22.2	0.29–0.34	0.32	023
		no	0–3	31.0–32.5	31.9	0.29–0.38	0.32	002
75	25	yes	2–1	38.8–41.0	39.9	0.54–0.59	0.55	026
		* no	0–3	39.8–44.2	41.5	0.45–0.48	0.47	037

a Dry weight basis.
b * = Threshold Reaction Level: moisture level for this NC/Compost ratio with no positive reactions and at least one positive reaction at the next lower moisture level.
c Positive reaction defined by container damage, pipe or end caps must fragment into at least two distinct pieces.
d Samples taken during container loading, determined by loss in weigh method.
e Average if multiple trials performed per moisture level.
f Blend 010a obtained by drying blend 010, dry weight composition same as 010.
NA Range not applicable to single trial.

Table 5 Explosive Reactivity of Nitrocellulose/Compost Mixture Blends Determined By Deflagration to Detonation Test (con't)

NC (%)[a]	Compost (%)[a]	Sample Reactive[b] yes/no	Test Reactions positive –negative[c]	Moisture (%)[d]		Bulk Density (gm/cc)[e]		Blend No.[f]
				Range	Avg.	Range	Avg.	
COMPOST MIXTURE #3 Dry Weight Composition of Compost: 2% Cow Manure, 65% Saw Dust, 33% Straw								
25	75	no	0–3	9.1–9.5	9.3	0.25–0.28	0.26	033
		no	0–3	16.0–20.5	17.5	0.25–0.31	0.28	016
50	50	yes	2–1	21.2–25.0	22.8	0.32–0.33	0.32	004
		* no	0–3	23.6–29.8	26.0	0.33–0.36	0.35	014
		no	0–3	30.3–32.7	31.5	0.30–0.32	0.31	003
75	25	yes	3–0	27.6–30.1	28.8	0.35–0.39	0.37	005
		yes	1–2	36.9–39.1	38.2	0.42–0.45	0.44	015
		yes	1–0	37.0–42.1	39.6	NA	0.50	008
		* no	0–3	42.1–45.3	43.8	0.52–0.59	0.56	021
		no	0–1	44.0–46.6	45.2	NA	0.53	010a
		no	0–3	48.8–51.2	50.6	0.56–0.67	0.63	010

a Dry weight basis.
b * = Threshold Reaction Level: moisture level for this NC/Compost ratio with no positive reactions and at least one positive reaction at the next lower moisture level.
c Positive reaction defined by container damage, pipe or end caps must fragment into at least two distinct pieces.
d Samples taken during container loading, determined by loss in weigh method.
e Average if multiple trials performed per moisture level.
f Blend 010a obtained by drying blend 010, dry weight composition same as 010.
NA Range not applicable to single trial.

Table 6 Hot Wire[a] Ignition Tests of NC/Compost Mixtures

Trial No.	Test Sample [b]				Confinement[c]	Observations
	NC (%)[d]	Compost (%)[d]	Mixture No.[e]	Moisture (%)		
1	75	25	3	28.8	None	no sustained burning after ignition source removed
2					Partial	
3	50	50	3	22.8	None	
4					Partial	
5	50	50	3	22.8	None	sample displaced [f], no sustained burning
6	50	50	2	31.9	None	no sustained burning after ignition source removed
7					Partial	
8	50	50	3	31.5	None	
9					Partial	

a Hot wire coil formed from 0.012" nichrome wire, ≈3/8" diameter.
b Eight ounces of sample in a conical pile approximately 5-6" high, 8-9" diameter on a metal plate.
c Steel cap, weighing 7.5 lb. placed on conical pile; resultant sample thickness 1.38" to 1.5".
d Dry weight basis nominal percentages.
e Compost mixture #3: 2% cow manure, 65% saw dust, 33% straw.
Compost mixture #2: 45% horse manure, 55% straw.
f Nichrome wire in a 12 gram bag igniter.

Table 7 Initiation Sensitivity of Nitrocellulose

Probit Impact Initiation Data for Dry NC Linters (13.15–13.20 N_2)		
Energy, ft.-lbs	Percent Initiation	Number of Trials
* 0.26	0	20
0.41	10	10
0.53	20	10
0.71	30	10
0.95	50	10
1.30	80	10
1.54	100	10

Probit Friction Initiation Data for Dry NC Linters (13.15–13.20 N_2)		
Energy, psi @8 fps	Percent Initiation	Number of Trials
* 16832	0	20
20703	20	10
28125	40	10
32877	60	10
42500	70	10
48837	90	10
58201	100	10

Probit Electrostatic Initiation Data for Dry NC Linters (13.15–13.20 N_2)		
Energy, Joules	Percent Initiation	Number of Trials
* 0.062	0	20
0.120	5	20
0.260	15	20
0.630	50	10
0.890	60	10
1.250	80	10
3.130	100	10

* Threshold initiation level (TIL); established by 20 consecutive initiation failures at test level indicated with at least one initiation at the next higher test level.

Table 7 Initiation Sensitivity of Nitrocellulose (con't)

Probit Impact Initiation Data for 30% Water-Wet NC Linters (13.15-13.20 N_2)		
Energy, ft.-lbs	Percent Initiation	Number of Trials
* 3.10	0	20
3.90	10	10
4.90	20	10
6.10	60	10
7.70	90	10

Probit Friction Initiation Data for 30% Water-Wet NC Linters (13.15-13.20 N_2)		
Energy, psi @8 fps	Percent Initiation	Number of Trials
* 83978	0	20
107040	10	10
121979	20	10
136048	90	10
146055	100	10

Probit Electrostatic Initiation Data for 30% Water-Wet NC Linters (13.15-13.20 N_2)		
Energy, Joules	Percent Initiation	Number of Trials
* 0.13	0	20
0.26	10	10
0.663	20	10
1.28	40	10
1.93	70	10
3.14	90	10

* Threshold initiation level (TIL); established by 20 consecutive initiation failures at test level indicated with at least one initiation at the next higher test level.

Table 8 Initiation Sensitivity of 50:50 NC/Compost

Probit Impact Initiation Data for Dry 50:50 NC/Compost Mixture #2		
Energy, ft.–lbs	Percent Initiation	Number of Trials
* 0.40	0	20
0.80	10	10
1.04	30	10
1.30	40	10
1.60	60	10
2.00	80	10

Probit Friction Initiation Data for Dry 50:50 NC/Compost Mixture #2		
Energy, psi @8 fps	Percent Initiation	Number of Trials
* 17500	0	20
19150	5	20
23600	30	10
29200	50	10
33550	70	10
42500	90	10

Probit Electrostatic Initiation Data for Dry 50:50 NC/Compost Mixture #2		
Energy, Joules	Percent Initiation	Number of Trials
* 0.066	0	20
0.13	10	10
0.26	30	10
0.29	50	10
0.39	70	10
0.66	90	10

* Threshold initiation level (TIL); established by 20 consecutive initiation failures at test level indicated with at least one initiation at the next higher test level.

Table 8 Initiation Sensitivity of 50:50 NC/Compost (con't)

Probit Impact Initiation Data for 30% Water-Wet 50:50 NC/Compost Mixture #2		
Energy, ft.-lbs	Percent Initiation	Number of Trials
* 4.90	0	20
6.10	10	10
7.70	30	10
9.60	50	10
12.20	60	10
14.40	90	10

Probit Friction Initiation Data for 30% Water-Wet 50:50 NC/Compost Mixture #2		
Energy, psi @8 fps	Percent Initiation	Number of Trials
* 87366	0	20
106061	10	10
119149	50	10
126027	70	10
141026	90	10

Probit Electrostatic Initiation Data for 30% Water-Wet 50:50 NC/Compost Mixture #2		
Energy, Joules	Percent Initiation	Number of Trials
* 0.663	0	20
0.91	10	10
1.28	40	10
1.35	50	10
1.93	80	10
3.14	90	10

* Threshold initiation level (TIL); established by 20 consecutive initiation failures at test level indicated with at least one initiation at the next higher test level.

Figure 1 NC/Compost Mixtures Reactivity Summary

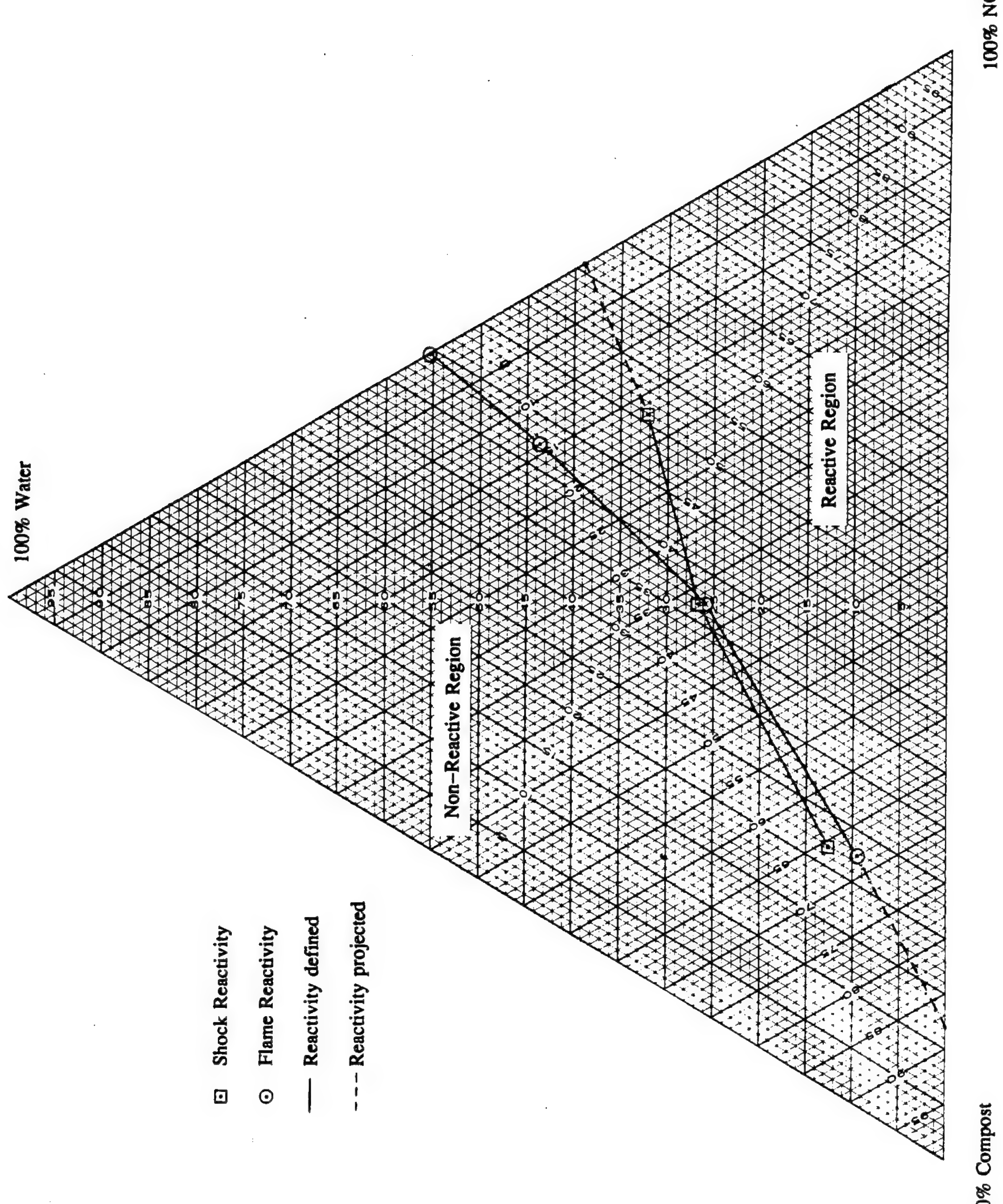


Figure 2 Test Scheme

1. Toxicity

a. Reviewed composition analysis data for each amendment to determine its potential for toxicity exposure to operating personnel.

2. Compatibility

a. Submitted individual compost amendments to modified Taliani test to determine chemical compatibility with nitrocellulose.

FAIL → REJECTED (none)

PASS → 3. DDT Flame Test for screening

3. DDT Flame Test for screening

a. Initial Screening – Performed closed pipe Deflagration to Detonation Test (DDT) to define potential explosive reactivity to flame.

b. Each amend mixture was tested in a 50:50 ratio of NC:Compost amendment mixture at 30% moisture level.

c. Determined the most reactive amendment mixture. Ranked the other amendment mixtures with regards to explosive severity.

LESS REACTIVE → Mixtures #1 & #2

MORE REACTIVE → Mixture #3 → 4. Critical Diameter Shock Test Series

4. Critical Diameter Shock Test Series

a. Mixtures of NC/Compost amendments tested to establish if the mixture would propagate an explosion by induced shock.

b. Explosive reactivity defined for diameter, composition and moisture content.

c. Series of trials at 1/2" increments up to 2.5" in diameter for each composition. Three consecutive failure trials defined a no reaction level.

Figure 2 Test Scheme (con't)

5. DDT Flame Test Series

a. Determined the propensity to transit from slow burning to an explosion in the Deflagration to Detonation Test (DDT) as function of composition and moisture.

b. Three trials were conducted at each test mixture. Three consecutive failure trials defined a no reaction level.

6. Selected Verification Tests

a. Verified explosive reactivity of NC/Compost amendment mixtures #1 and #2 in selective Critical Diameter and DDT tests.

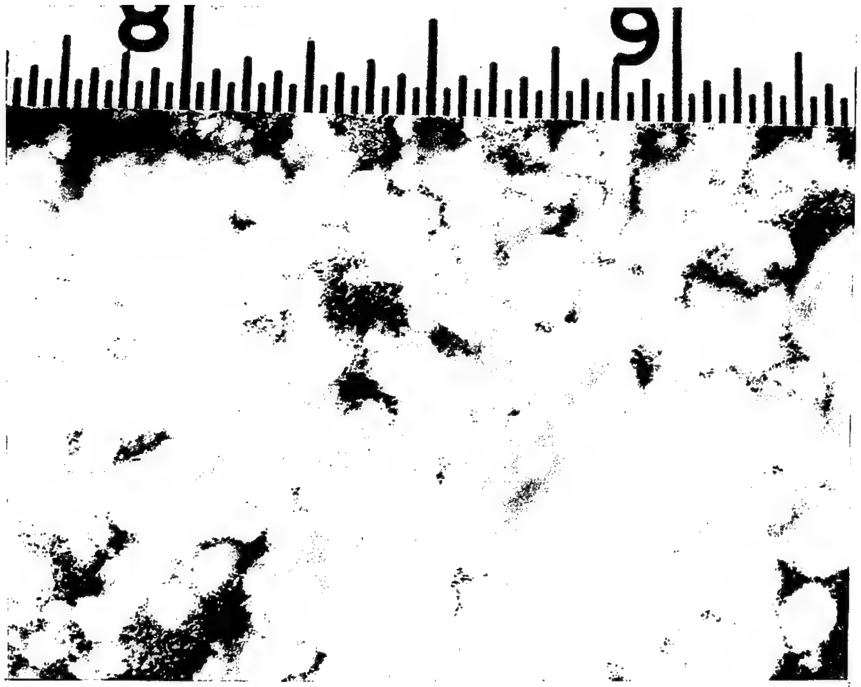
7. Initiation Sensitivity Tests

a. The impact, sliding friction, and electrostatic discharge initiation sensitivity were defined for NC and NC/amendment mixture #2 at dry and 30% moisture levels.

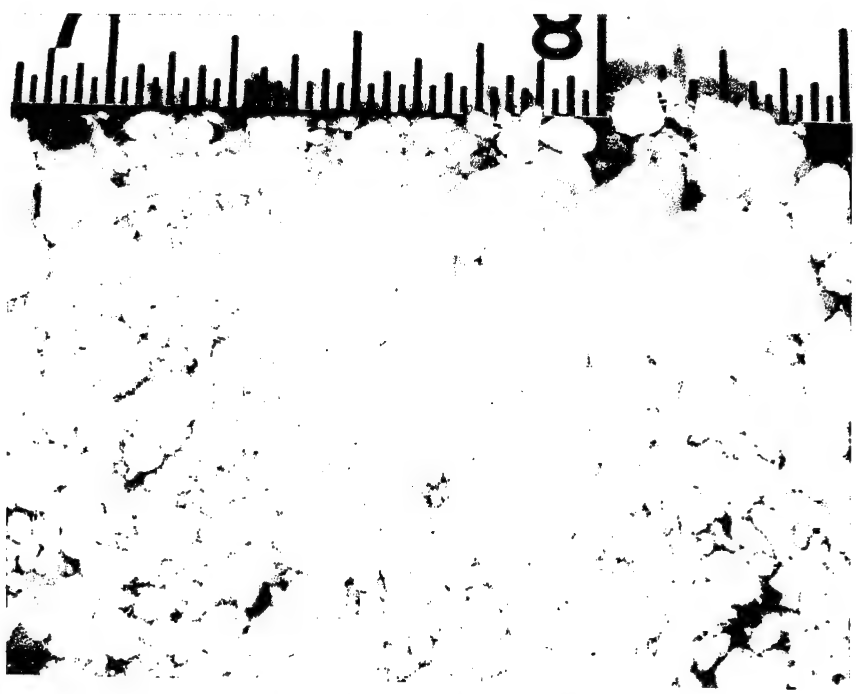
8. Data Analysis and Recommendations

a. The explosive reactivity of NC/Compost amendment mixtures was defined as function of NC and moisture level.

Figure 3 Examples of NC/Compost Mixtures



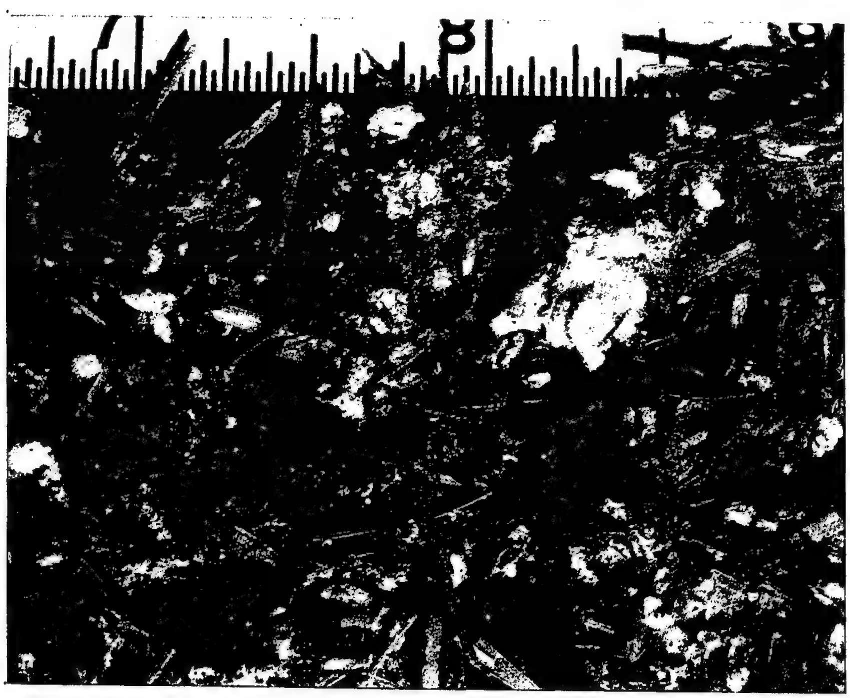
3a. NC/Compost Mixture #0
NC @ 37% Moisture
(13.15% N from linters)



3b. NC/Compost Mixture #0
NC @ 59% Moisture
(13.15% N from linters)

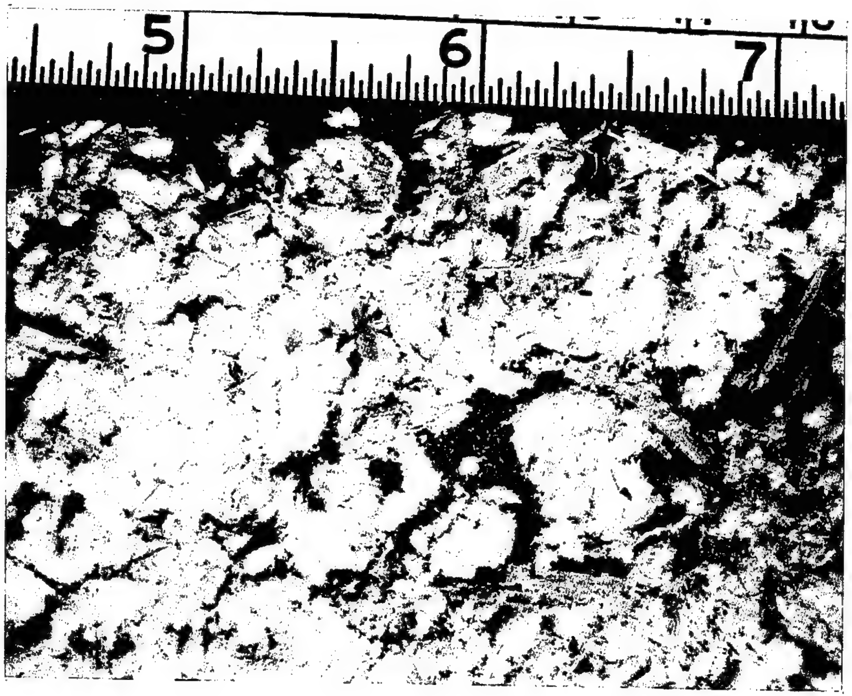
Figure 3 Examples of NC/Compost Mixtures (con't)

3c. 25/75 NC/Compost Mixture #1
@ 24% Moisture



3d. 50/50 NC/Compost Mixture #2
@ 32% Moisture

Figure 3 Examples of NC/Compost Mixtures (con't)



3e. 75/25 NC/Compost Mixture #3
@ 18% Moisture

Figure 4 Explosive Reactivity of NC/Compost Mixtures to Shock Stimulus
Determined by Critical Diameter Test

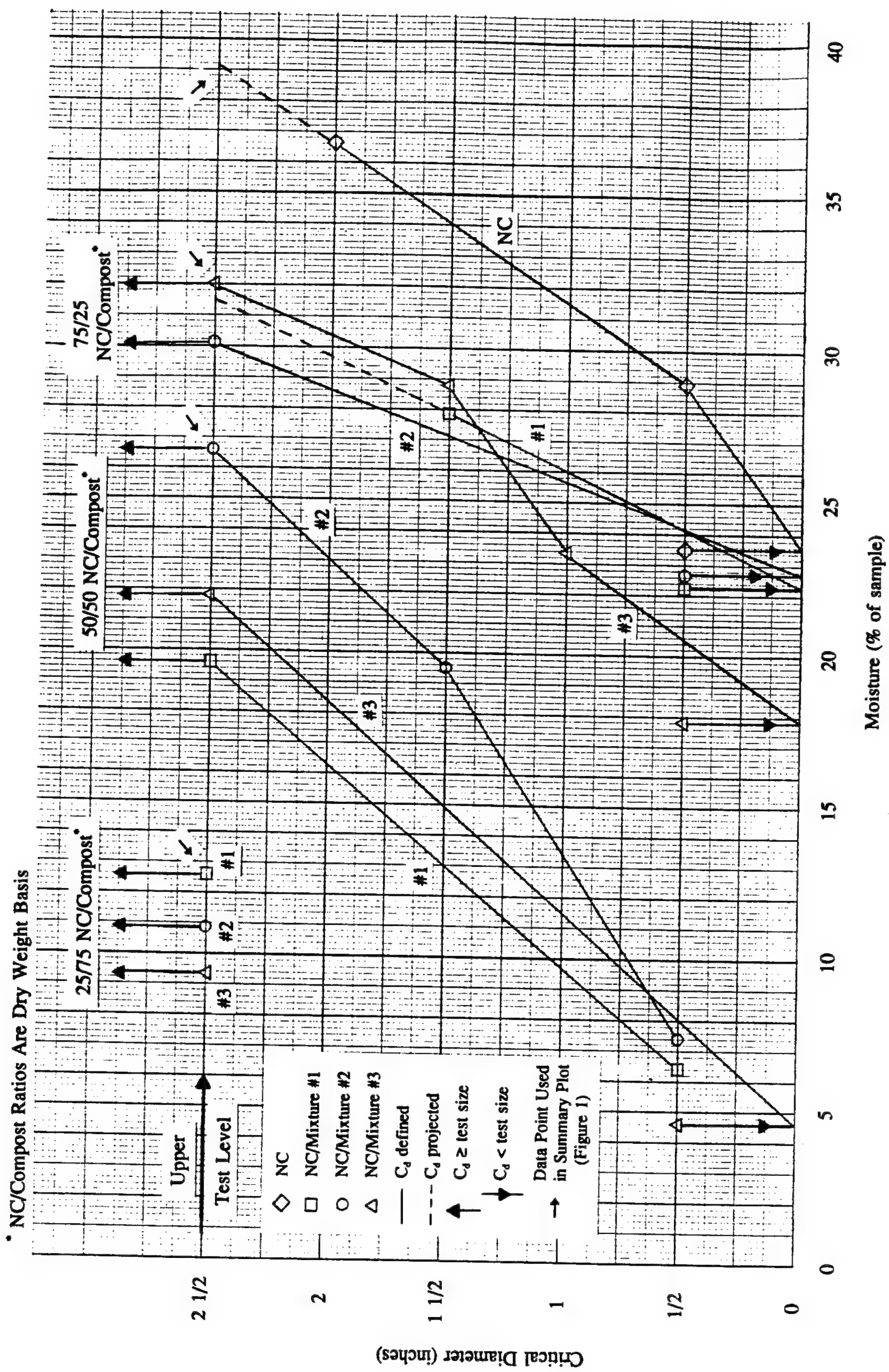


Figure 5 Examples of Critical Diameter Test Reactions

5a. Positive Reaction
2" x 24" pipe split full length
75/25 NC/Compost Mixture #3
@ 28.8% Moisture

5b. Failure Reaction
2" x 24" pipe partially split
75/25 NC/Compost Mixture #3
@ 39.6% Moisture

Figure 6 Explosive Reactivity of NC/Compost Mixtures to Flame Stimulus Determined by Closed Pipe Deflagration to Detonation Test

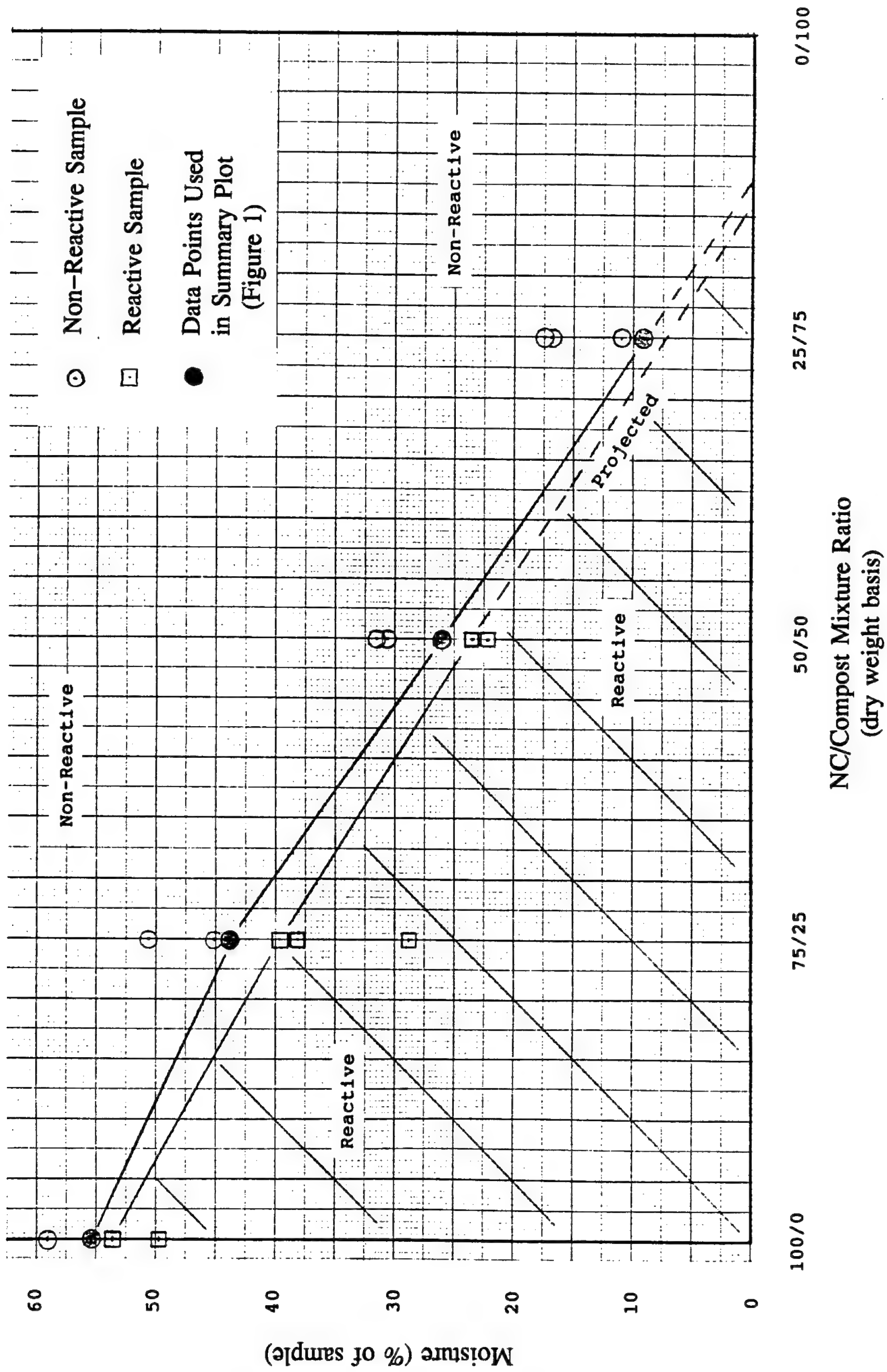
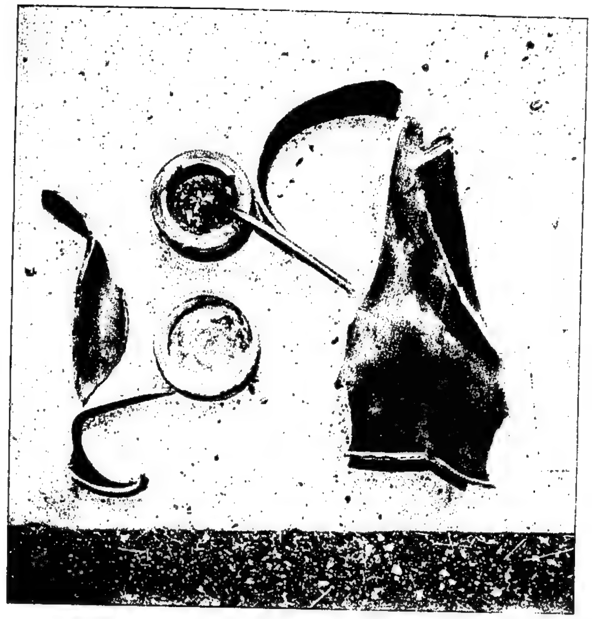
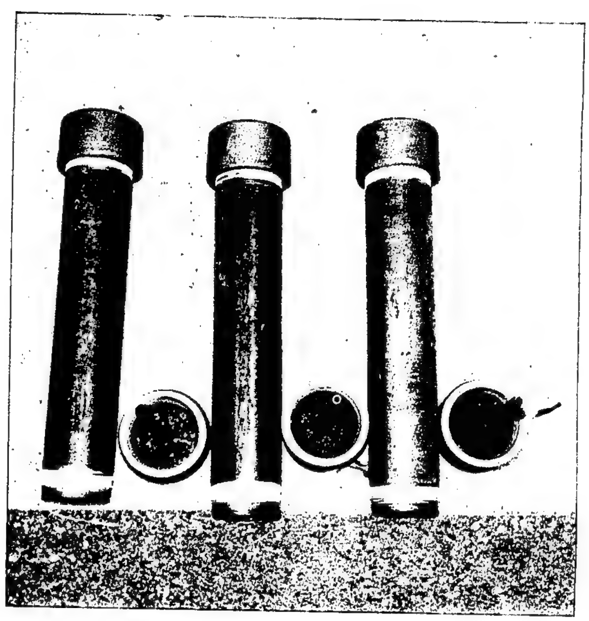


Figure 7 Examples of Deflagration to Detonation Test Reactions

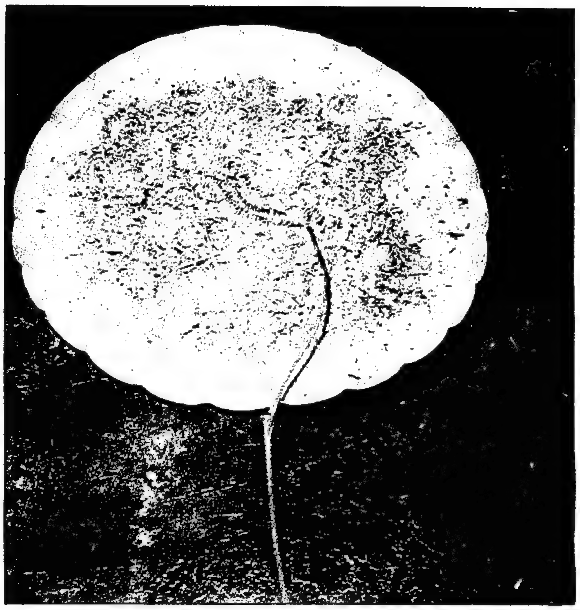


7a. Positive Reaction
Container fragmented into multiple pieces
75/25 NC/Compost Mixture #3
@ 39.6% Moisture

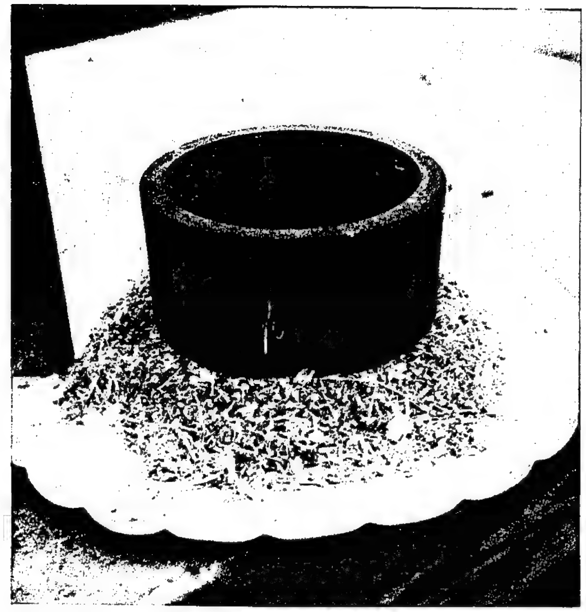


7b. Failure Reaction
Container not fragmented
50/50 NC/Compost Mixture #3
@ 26.0% Moisture
Caps Removed After Test

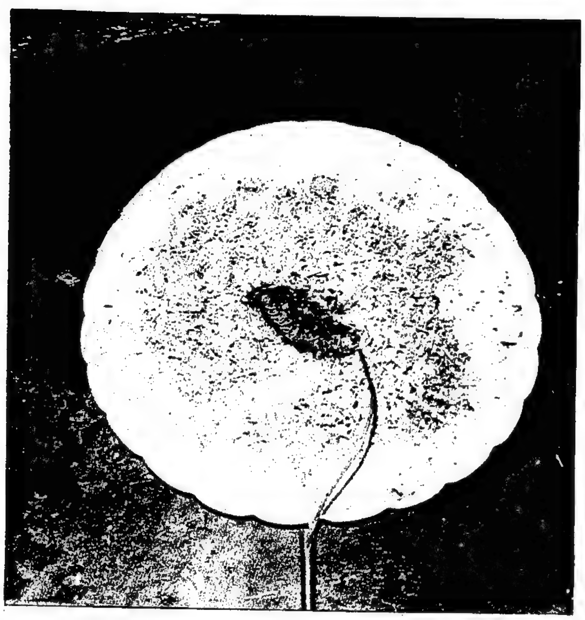
Figure 8 Examples of Hot Wire Ignition Tests



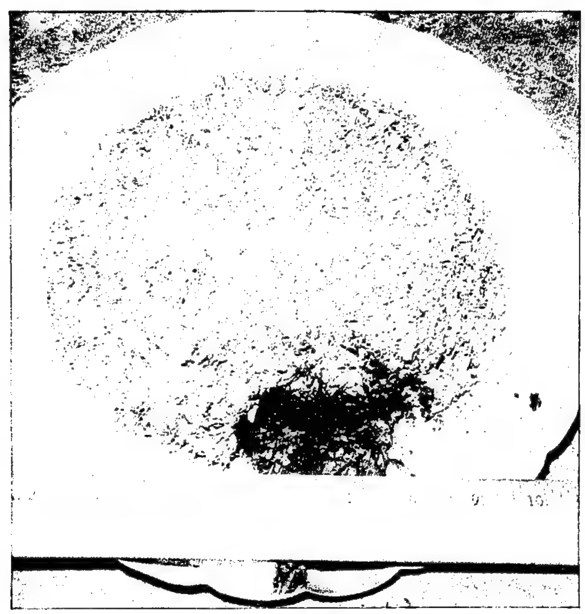
8a. Before Ignition
Hot Wire Coil On Surface



8b. Before Ignition
Weight On Sample



8c. After Ignition – Trial 6
No Weight, Burning Not Sustained
50/50 NC/Compost Mixture #2
@ 31.9% Moisture



8d. After Ignition – Trial 4
With Weight, Burning Not Sustained
Weight Removed For Photo
50/50 NC/Compost Mixture #3
@ 22.8% Moisture

Figure 9 Initiation Sensitivity of Dry and Water–wet NC

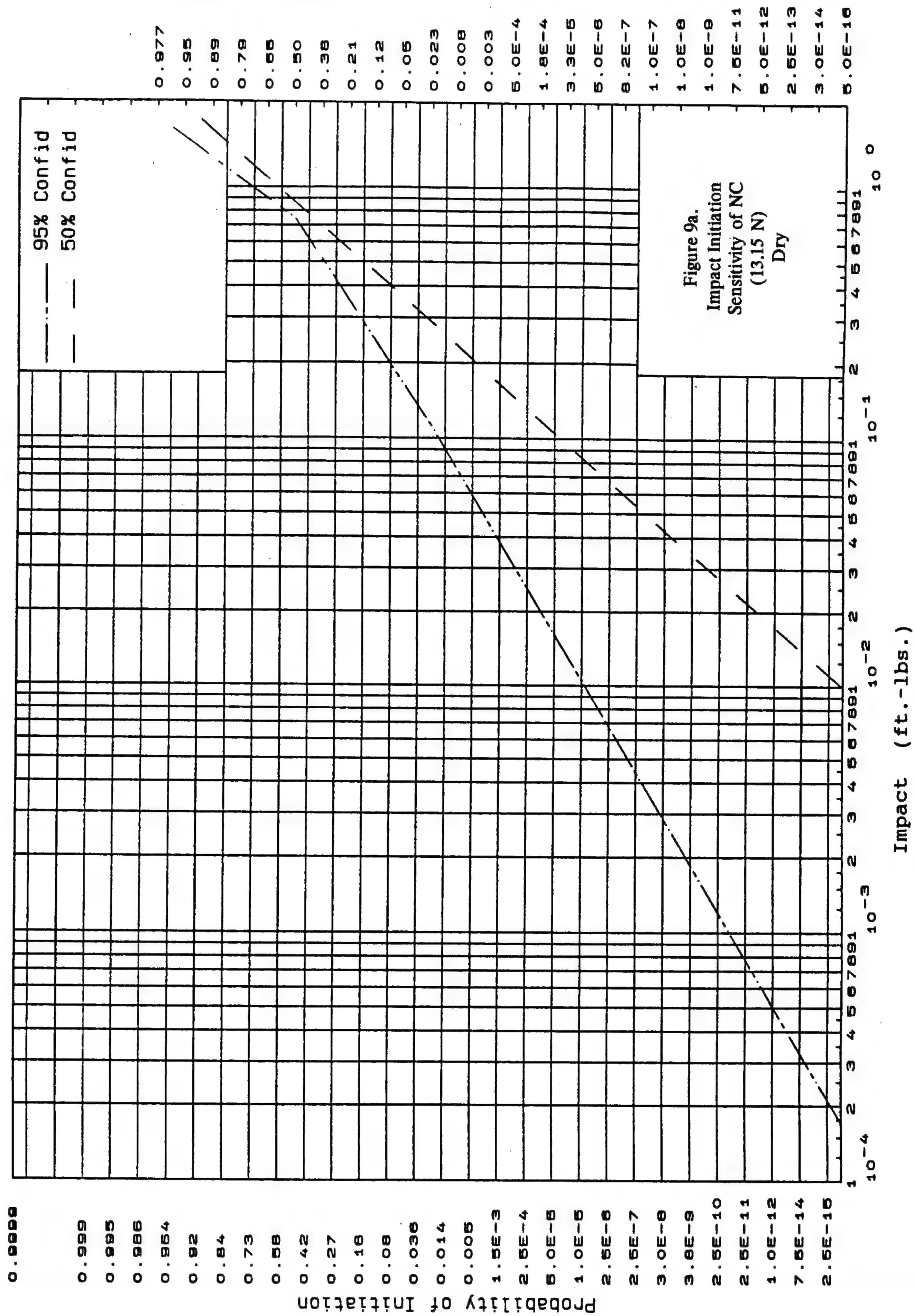


Figure 9 Initiation Sensitivity of Dry and Water–wet NC (con't)

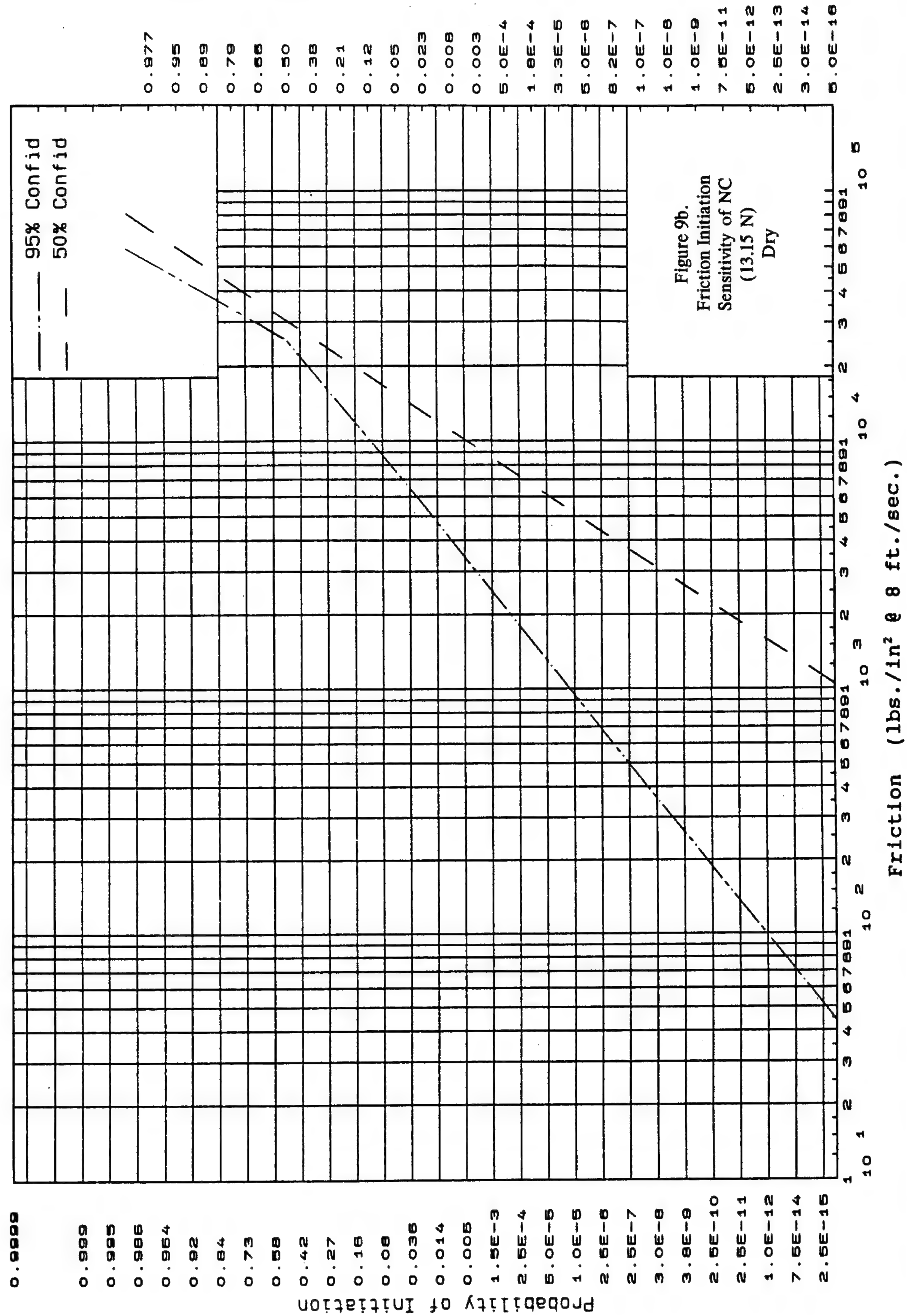


Figure 9 Initiation Sensitivity of Dry and Water–wet NC (con't)

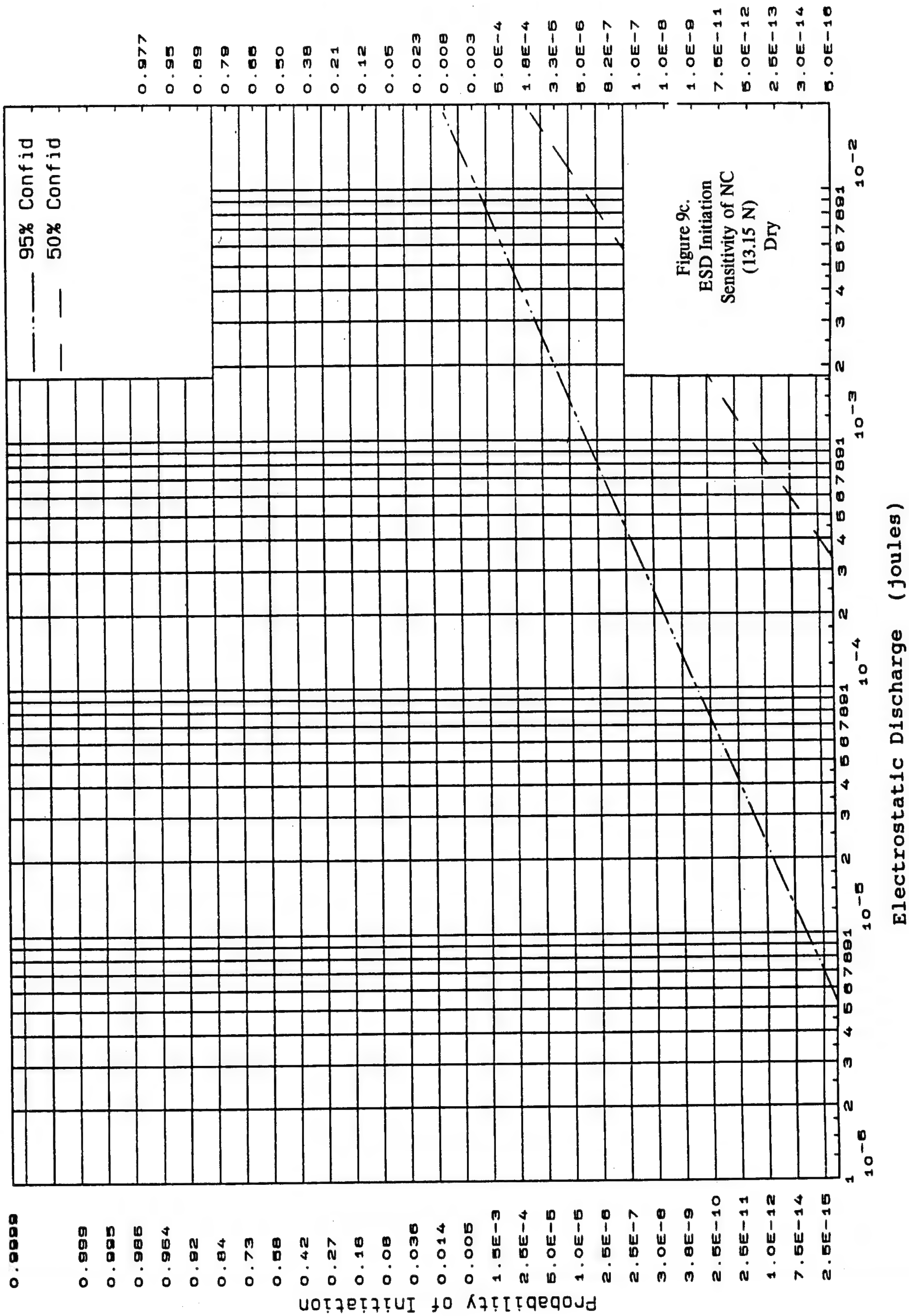


Figure 9 Initiation Sensitivity of Dry and Water–wet NC (con't)

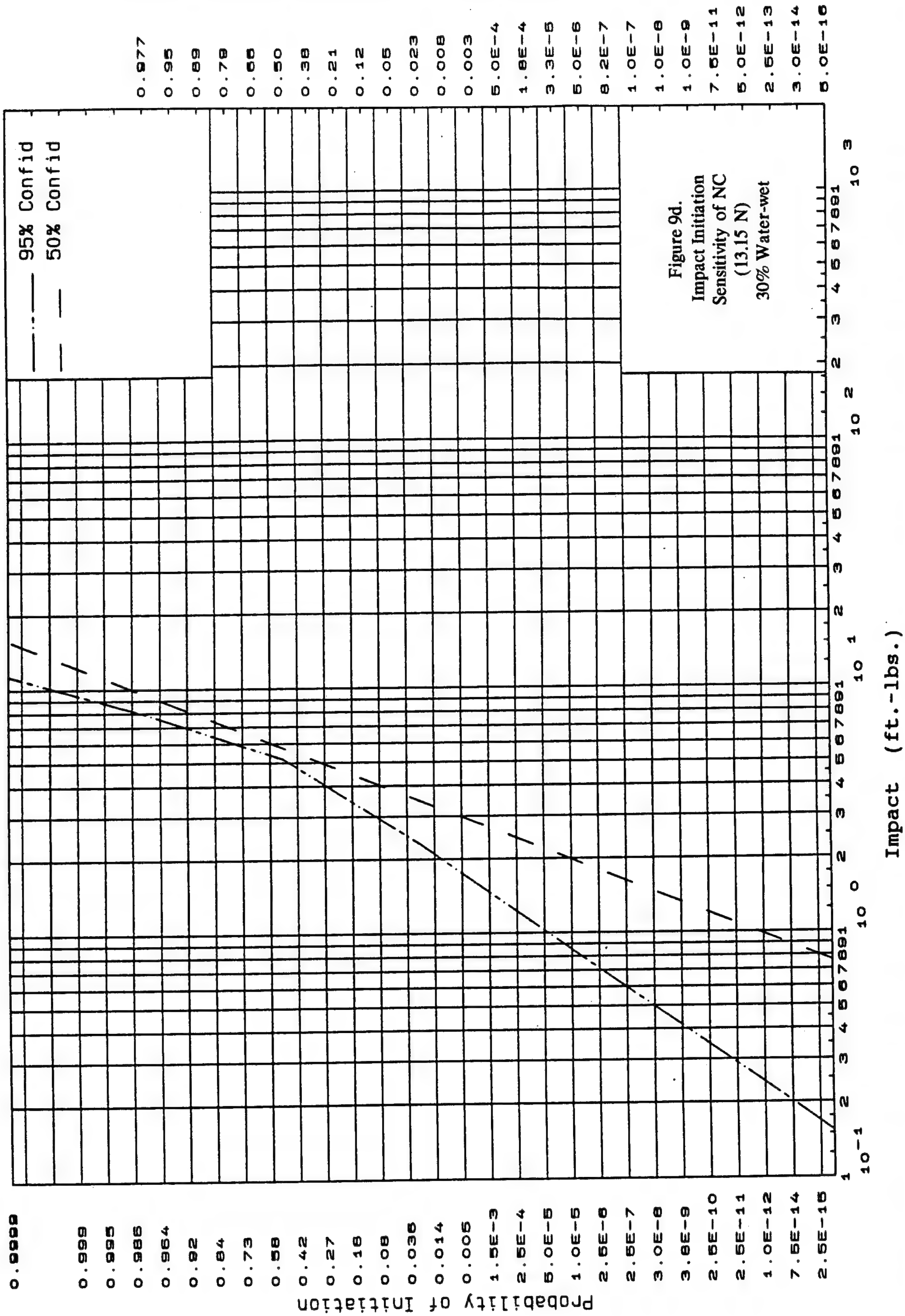


Figure 9 Initiation Sensitivity of Dry and Water–wet NC (con't)

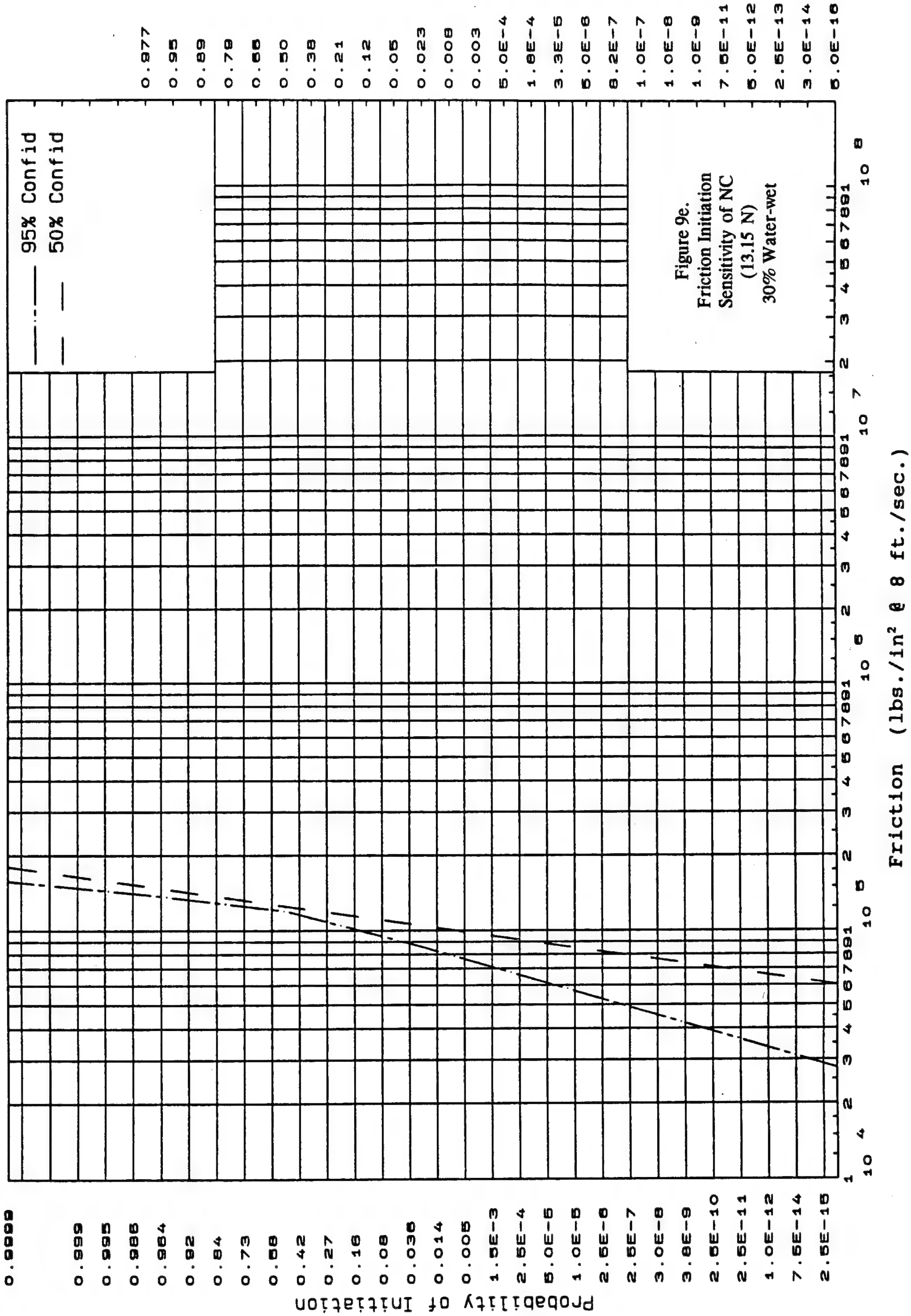


Figure 9 Initiation Sensitivity of Dry and Water–wet NC (con't)

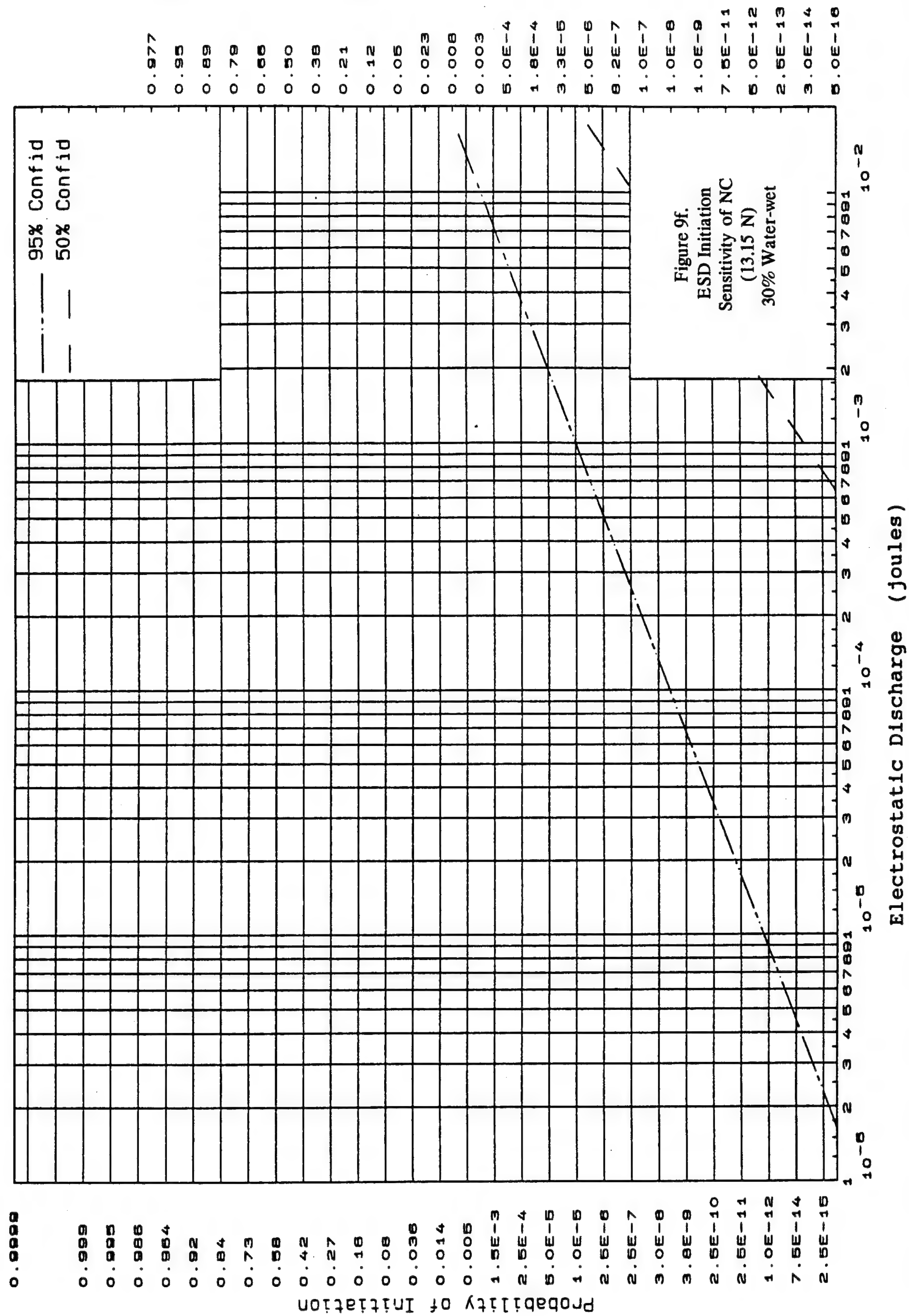


Figure 9f.
ESD Initiation
Sensitivity of NC
(13.15 N)
30% Water-wet

Figure 10 Initiation Sensitivity of Dry and Water-wet 50/50* NC/Compost Mixture

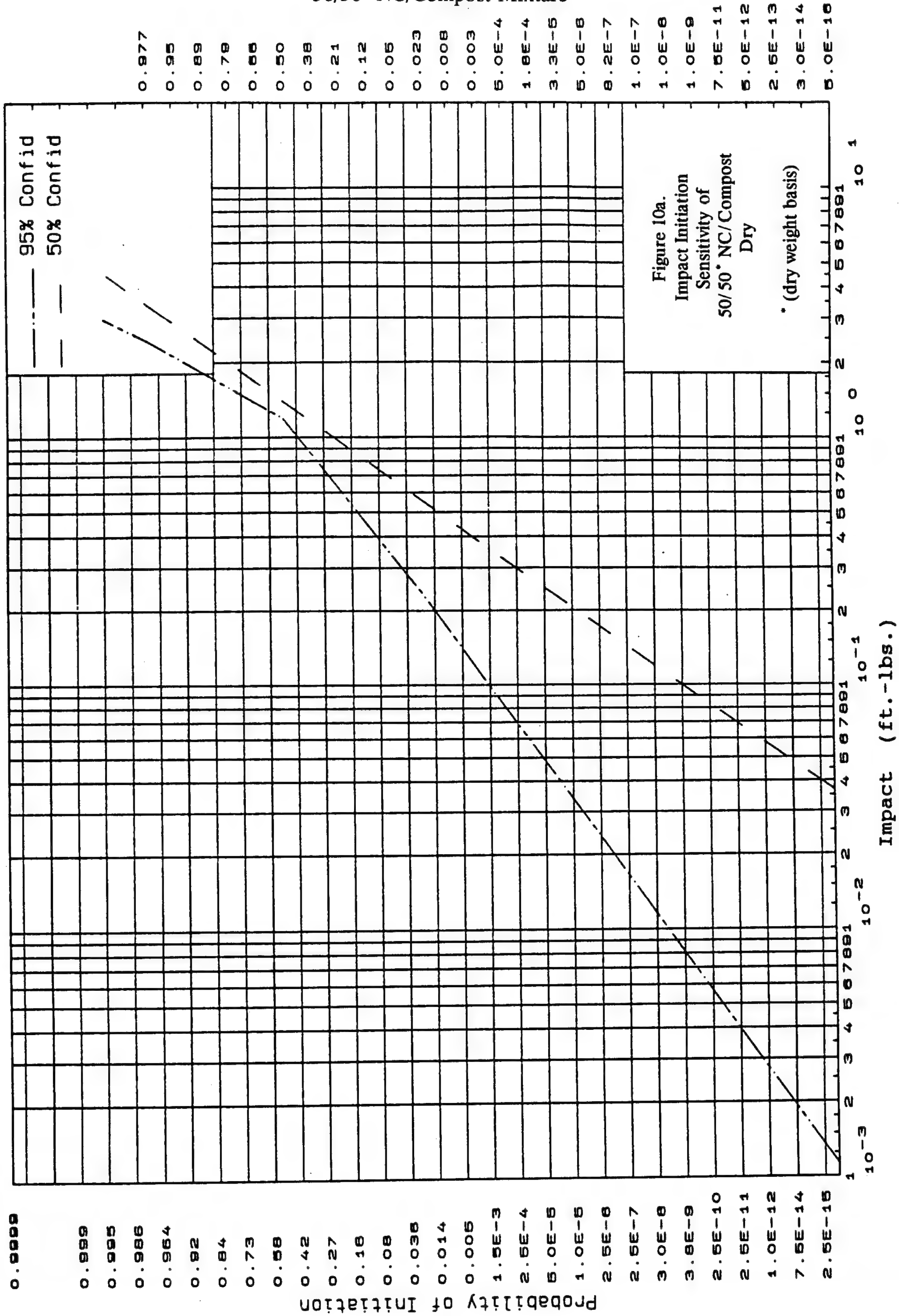


Figure 10 Initiation Sensitivity of Dry and Water–wet
50/50* NC/Compost Mixture (con't)

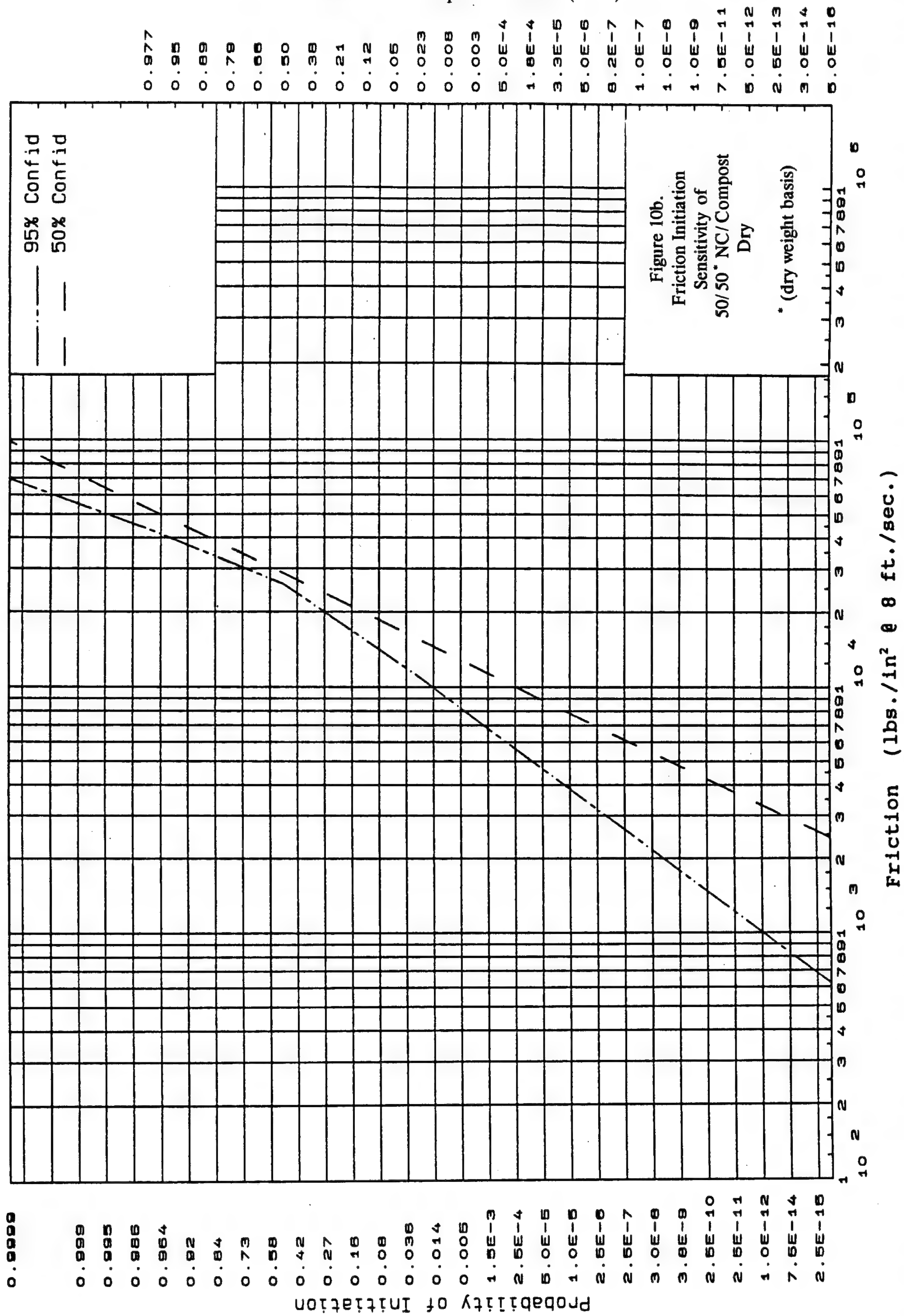


Figure 10 Initiation Sensitivity of Dry and Water–wet
50/50* NC/Compost Mixture (con't)

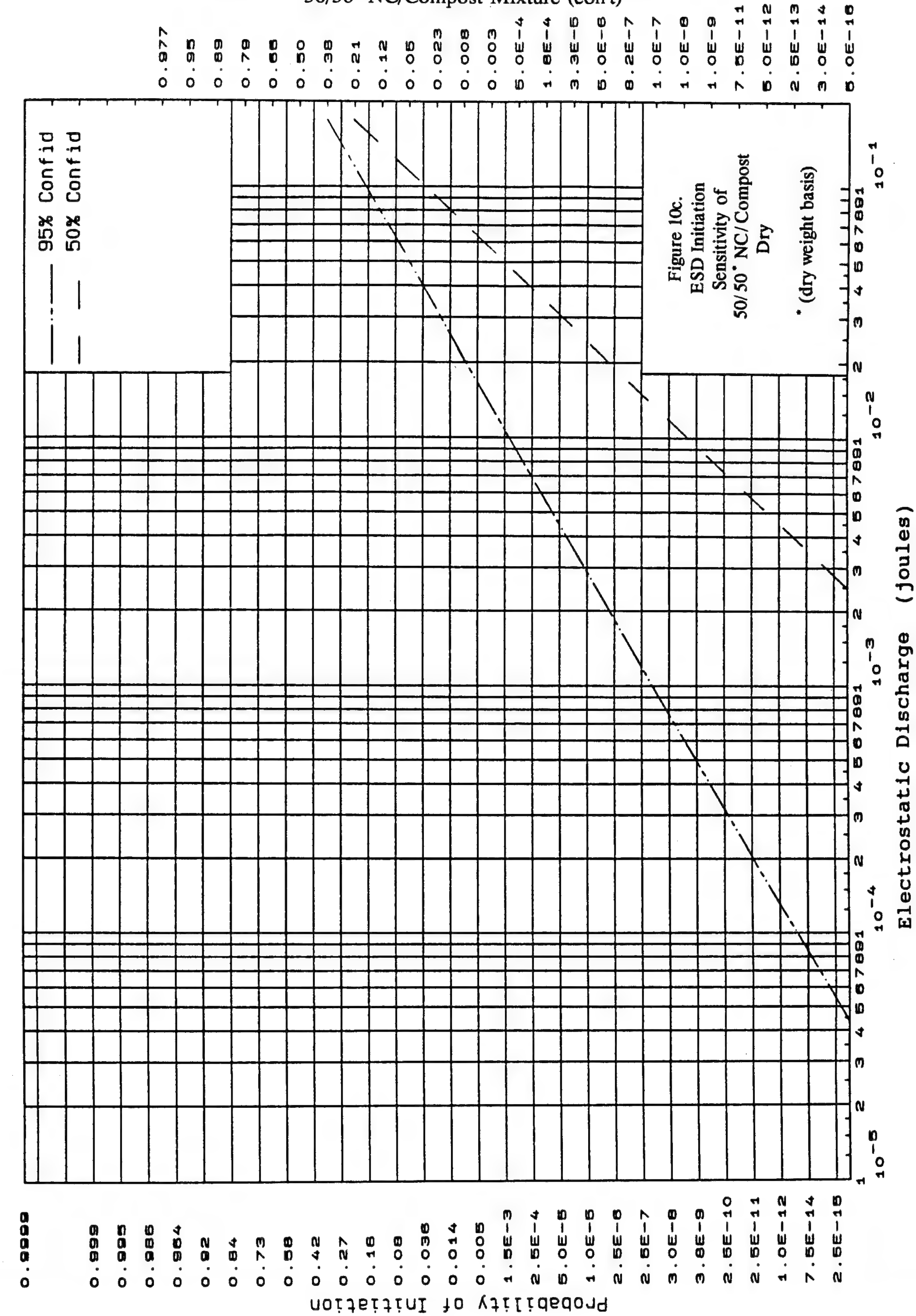


Figure 10 Initiation Sensitivity of Dry and Water–wet 50/50* NC/Compost Mixture (con't)

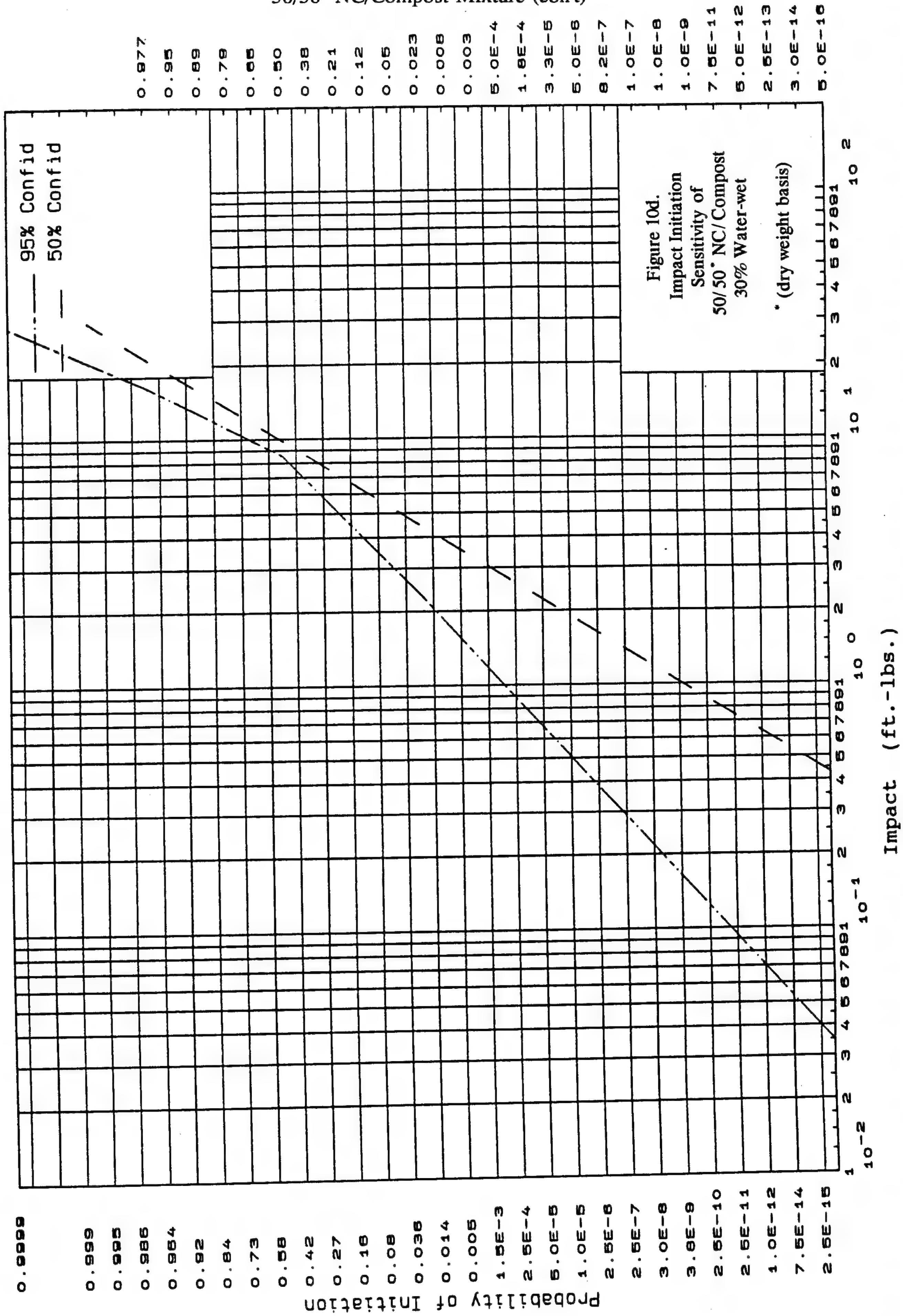


Figure 10d.
Impact Initiation Sensitivity of 50/50* NC/Compost 30% Water-wet

* (dry weight basis)

Figure 10 Initiation Sensitivity of Dry and Water–wet 50/50* NC/Compost Mixture (con't)

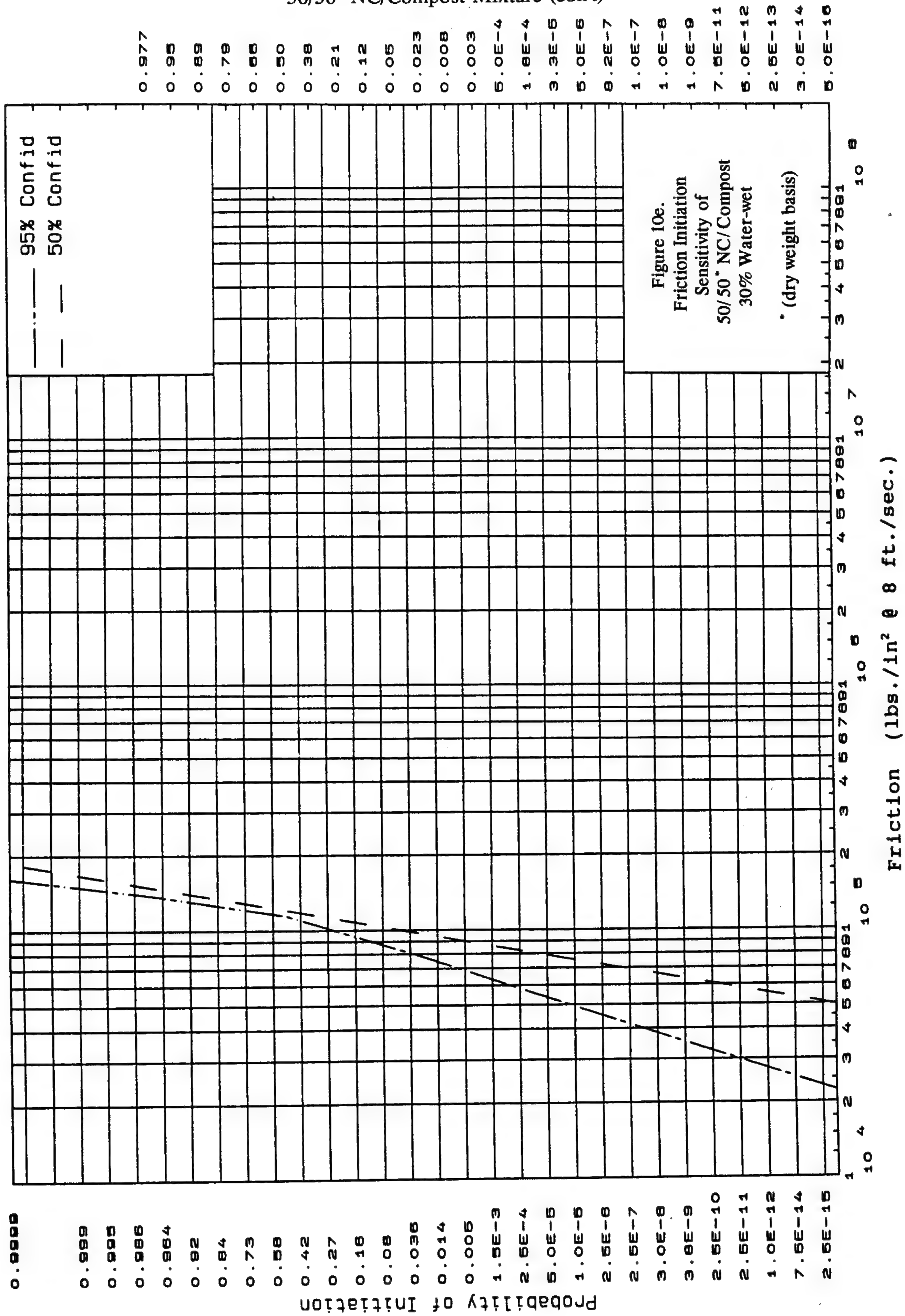


Figure 10 Initiation Sensitivity of Dry and Water–wet
50/50* NC/Compost Mixture (con't)

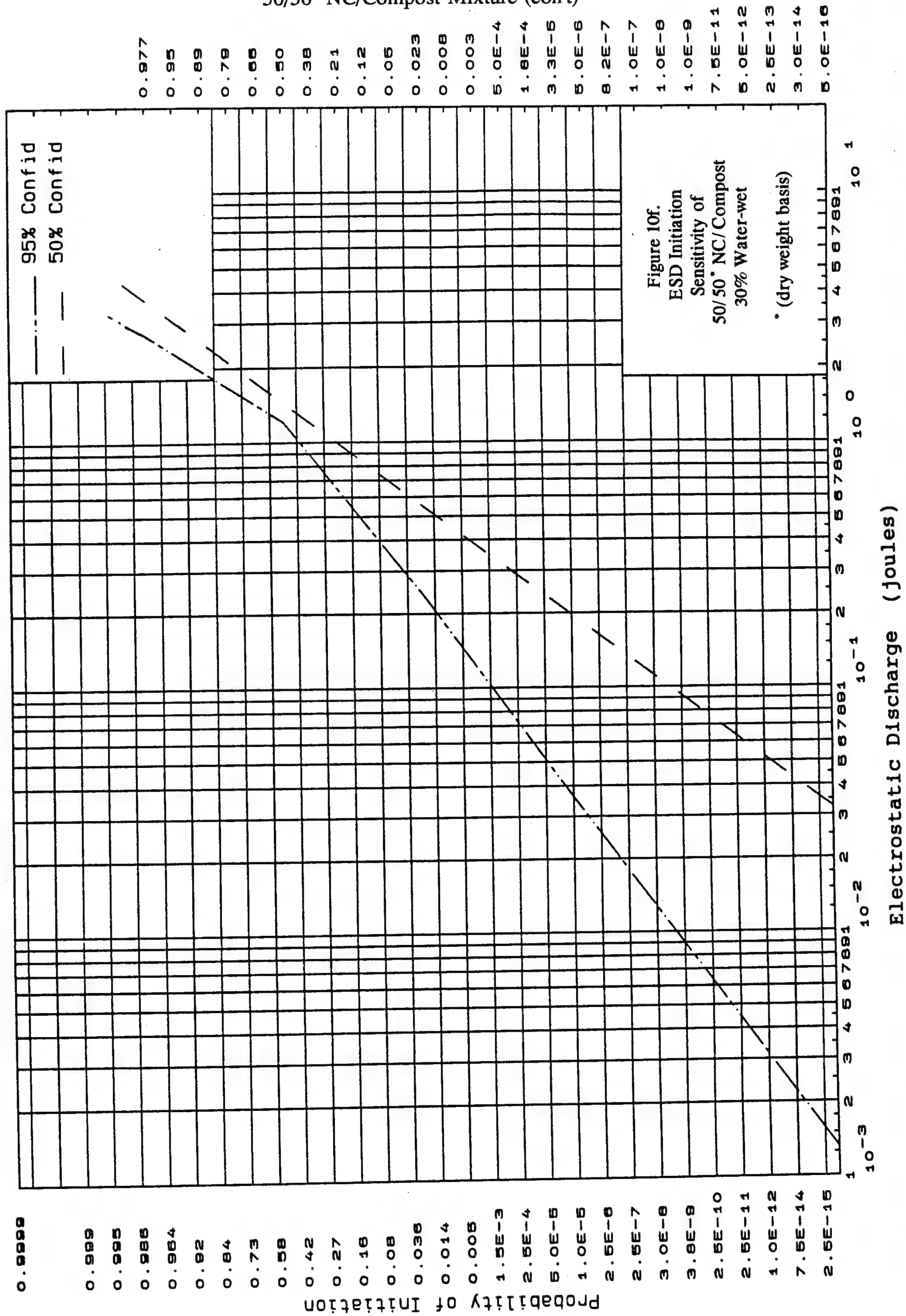


Figure 10f.
ESD Initiation
Sensitivity of
50/50* NC/Compost
30% Water-wet

* (dry weight basis)

Appendix A

Compost Amendment Composition and Compatibility Data

Table 1

Cow Manure

Parameter/units	Range[1] Dry Basis	As-is Basis
Density, lb/ft^3	14	51
Solids, %	100.0	23.9
Moisture, %	0.0	76.1
Water Holding Capacity, %	243.1	70.9
pH (1:1 H_2O), Std. units	—[2]	6.38
Organic Matter, %	79.3	19.0
Conductivity, mmhos/cm	—	2.8
Carbon Nitrogen (C:N) Ratio, W:W	37.4	37.4
Total nitrogen, %	1.145	0.274
Phosphorus, %	0.153	0.037
Potassium, %	0.434	0.104
Sodium, %	0.116	0.028
Calcium, %	0.711	0.170
Magnesium, %	0.157	0.038
Copper, mg/kg	5.5	1.3
Manganese, mg/kg	44.6	10.7
Iron, mg/kg	2290.2	547.4
Zinc, mg/kg	34.7	8.3

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Table 1 (Continued)

Cow Manure

Parameter/units	Range[1]	
Lead, mg/kg	<8.0	<1.9
Chromium, mg/kg	<8.0	<1.9
Cadmium, mg/kg	<0.8	<0.2
Nickel, mg/kg	<4.0	<1.0

[1] Data may represent analyses of several source materials within each category.

[2] Not analyzed.

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Table 2

Horse Manure

Parameter/units	Range[1]	
	Dry Basis	**As-is Basis**
Density, lb/ft^3	8	34
Solids, %	100.0	52.1
Moisture, %	0.0	47.9
Water Holding Capacity, %	253.2	71.7
pH (1:1 H_2O), Std. units	—[2]	8.84
Organic Matter, %	83.0	43.2
Conductivity, mmhos/cm	18.5	5.7
Carbon Nitrogen (C:N) Ratio, W:W	—	18.5
Total nitrogen, %	2.603	1.356
Phosphorus, %	—	—
Potassium, %	—	—
Sodium, %	—	—
Calcium, %	—	—
Magnesium, %	—	—
Copper, mg/kg	—	—
Manganese, mg/kg	—	—
Iron, mg/kg	—	—
Zinc, mg/kg	—	—

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Table 2 (Continued)

Horse Manure

Parameter/units	Range[1]	
Lead, mg/kg	—	—
Chromium, mg/kg	—	—
Cadmium, mg/kg	—	—
Nickel, mg/kg	—	—

[1] Data may represent analyses of several source materials within each category.

[2] Not analyzed.

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Appendix A (con't)

Table 3

Sawdust

Parameter/units	Range[1]	
	Dry Basis	As-is Basis
Density, lb/ft^3	9-12	12-40
Solids, %	100	42.9-96.0
Moisture, %	0.0	4.0-57.1
Water Holding Capacity, %	296.8-299.6	74.8-75.0
pH (1:1 H_2O), Std. units	—[2]	4.34-6.11
Organic Matter, %	98.8-99.8	42.7-95.2
Conductivity, mmhos/cm	—	0.1-2.0
Carbon Nitrogen (C:N) Ratio, W:W	254.1-6251.1	254.1-6251.1
Total nitrogen, %	<0.02-0.227	<0.02-0.171
Phosphorus, %	0.001-0.024	0.001-0.020
Potassium, %	0.005-0.150	0.004-0.125
Sodium, %	0.002-0.049	0.002-0.047
Calcium, %	0.023-0.170	0.020-0.073
Magnesium, %	0.002-0.017	0.002-0.014
Copper, mg/kg	<2.0	<0.9-<1.7
Manganese, mg/kg	8.3-95.4	6.9-40.9
Iron, mg/kg	3.8-190.8	3.1-81.9
Zinc, mg/kg	1.9-7.1	1.6-3.0

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Appendix A (con't)

Table 3 (Continued)

Sawdust

Parameter/units	**Range[1]**	
Lead, mg/kg	<8.0	<3.4-<6.6
Chromium, mg/kg	<8.0	<3.4-<6.6
Cadmium, mg/kg	<0.8	<0.3-<0.7
Nickel, mg/kg	<4.0	<1.7-<3.3

[1] Data may represent analyses of several source materials within each category.

[2] Not analyzed.

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Appendix A (con't)

Table 4

Straw

Parameter/units	**Range[1]**	
	Dry Basis	**As-is Basis**
Density, lb/ft^3	5	9
Solids, %	100.0	92.4
Moisture, %	0.0	7.6
Water Holding Capacity, %	267.5	72.8
pH (1:1 H_2O), Std. units	—[2]	7.43
Organic Matter, %	88.2	81.5
Conductivity, mmhos/cm	—	2.2
Carbon Nitrogen (C:N) Ratio, W:W	70.5	70.5
Total nitrogen, %	0.725	0.670
Phosphorus, %	0.099	0.091
Potassium, %	2.078	1.920
Sodium, %	0.548	0.506
Calcium, %	0.153	0.141
Magnesium, %	0.052	0.048
Copper, mg/kg	—	—
Manganese, mg/kg	—	—
Iron, mg/kg	—	—
Zinc, mg/kg	—	—

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Table 4 (Continued)

Straw

Parameter/units	Range[1]	
Lead, mg/kg	—	—
Chromium, mg/kg	—	—
Cadmium, mg/kg	—	—
Nickel, mg/kg	—	—
Chromium, mg/kg	—	—

[1] Data may represent analyses of several source materials within each category.

[2] Not analyzed.

Source: Roy F. Weston, Inc., 1 Weston Way, West Chester, PA 19380–1499

Table 5
Taliani Test Results to Determine Compatibility of Compost Amendments

Amendment	**Test Result** (mm Hg)
Cow Manure	6
Horse Manure	2
Sawdust	2
Straw	2

The RAAP standard modified Taliani test measures the rate and magnitude of decomposition gases released when incompatible materials react chemically in a closed inert atmosphere for 23 hours at 200 degrees F. Resulting pressure must be less than 200 mm Hg for test materials to be determined compatible.

Source: Alliant Techsystems, Radford Army Ammunition Plant, Radford, VA 24141

Appendix B

BLENDING OF WATER WET NITROCELLULOSE/ORGANIC COMPOST MIXTURES

I PURPOSE

This document describes the procedures for equipment setup and check out, sample preparation, and blending of straw, sawdust, and/or organic materials with water–wet nitrocellulose in a polyethylene lined mixer (Figure 1).

A blending request sheet (see Table 1) shall be prepared and approved by Hazards Analysis supervisor showing specific test sample quantity and ratio of ingredients to be blended.

II SAFETY

Operators shall wear rubber gloves when handling organic compost amends for personal hygiene.

Operators shall wear dust mask during handling and loading operations if mix components are dry or may generate dust.

WARNING: Nitrocellulose (NC) shall be maintained ≈ 20 % water wet while being stored in the test area. Plastic lined leverpak drums containing water wet NC shall be sealed to minimize moisture loss. Drums will be turned every two weeks to prevent moisture stratification.

IV MIXER SETUP AND CHECK–OUT

1 Place the mixer in Test Pit and attach ground wire to blender frame.

2 Connect the power cord (**power OFF**) from the mixer over the Test Pit wall to the Ground Fault Circuit Interrupter receptacle located at the entrance to the test pit.

3 Visually inspect the polyethylene drum interior to assure it is clean and dry. If needed, clean by flushing with water and wiping dry.

4 Verify drum rotation is unobstructed. Ensure a uniform layer of grease is present on blender drive and ring gears. Position mixer barrel to the loading position and secure latch.

5 Set up the video monitoring equipment and remotely verify operation.

V SAMPLE PREPARATION

1 As requested from the blend sheet, weigh out the indicated amount of each compost amendment and water–wet nitrocellulose into individual plastic bags. Weigh out the required amount of water in an appropriate container.

2 Identify all ingredient bags, and water container with blend number, then tightly seal bags using masking tape or plastic wire tie, to minimize moisture loss.

3 Place ingredients in Conditioning Bay and retrieve as needed.

VI BLENDING

1 Transfer prepared ingredients (NC, amendments, and water) from the Conditioning Bay to the Test Pit. Transfer ingredients into mixer.

2 Pour the water evenly over the NC and amendments. Secure cover over drum opening.

3 From the Control Bay, energize mixer. Monitor operation on video to ensure proper rotation and blending time (10 minutes unless otherwise specified on the blend request). When proper blending time has been met, de–energize mixer.

NOTE: During initial blending operations it may be necessary to stop the mixer and inspect the blend to ensure it is homogeneous and not sticking to the sides of the drum. If the blend is sticking to the drum, using a polyethylene spatula, scrape the blend from the sides of the mixer drum and then resume blending operations.

4 Remove drum lid and position the drum to discharge completed blend into a plastic bag lined container.

5 Return to the control bay and start the mixer. Once the blend has been emptied into the polyethylene container as determined by video, stop the mixer.

6 If any blend material remains in mixer drum, use a polyethylene paddle to rake the remaining contents into the container.

7 Obtain a minimum of five (5) TV samples and three (3) content analysis samples from different locations in the master blend. Place each sample in a sealed and labeled plastic bag for transport to laboratory.

8 Seal plastic bag containing master blend with plastic wire tie to prevent moisture loss during storage. Label contents.

NOTE: Labels shall contain the following information:

a. Blend ID #
b. Date and Time
c. Weight
d. % of moisture

9 Place master blend on the counter surface in Sample Preparation Bay. Spread the bag contents as uniformly thin as possible (approx. 2–3" tk.).

NOTE: If sample is being stored over night it must be rotated periodically to prevent stratification. The master blend shall not be stored for more than 3 days prior to testing, to minimize biological activity.

10 Record date and time of blend preperation on the Blend Request Sheet.

11 Clean mixer and dismantle equipment.

Table 1

Date:______
Charge Code:______

Request For Blending

Compatibility with NC: _____ Composition ID______

Test No.______mm Hg ______ Blend No.________

Blend Size(dry wt.)____ Blend Date:_______

Ingredient	Wt. Dry	Water Wt.	Wt. to Mix
Nitrocellulose	____	______	_______
Amends	**Wt. Dry**	**Water Wt.**	**Wt. to Mix**
1.________	____	______	_______
2.________	____	______	_______
3.________	____	______	_______
4.________	____	______	_______

Blending Conditions:

Date:_______ RH:________ Temp.:______

TV Pulled:____ TV % ______avg.
____ TV %
____ TV %
____ TV %
____ TV %

Disposition of Blend:

Hazards Testing:__________

Laboratory:_____________

Operators:__________________

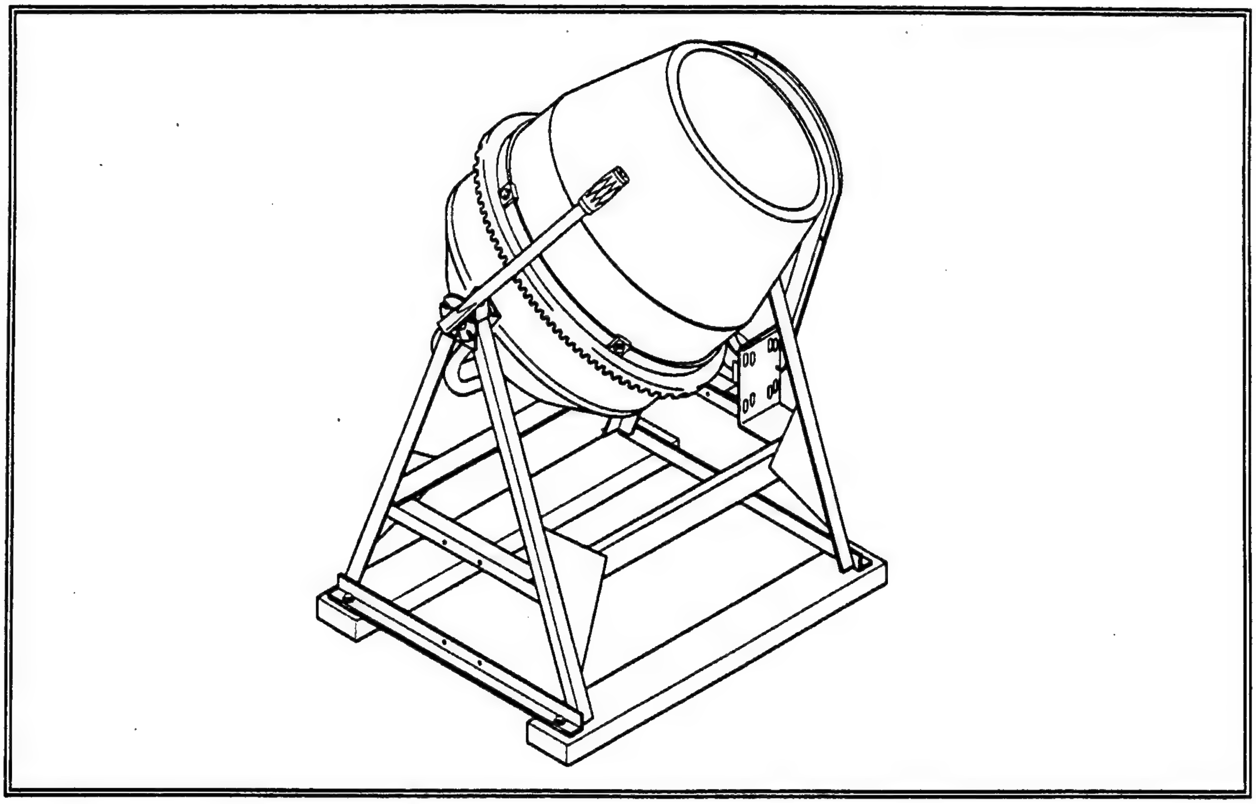
Approvals:

Hazards Supervisor:________________

Engineer: _______________________

Appendix B (con't)

FIGURE 1. MIXER – POLYETHYLENE–LINED DRUM



SOURCE:

POLYMAID COMPANY
1185 BASKINS ROAD
LARGO, FLORIDA 34648
1-800-940-7788

Appendix C

Nitrocellulose Content Determination of Nitrocellulose Compost Samples

ABSTRACT

The nitrocellulose content of 40 sets nitrocellulose compost samples was determined in support of a Hazards Evaluation, by acetone extraction.

EXPERIMENTAL

Samples 1 through 4 were analyzed as follows:

1. Weigh sample accurately.
1. Weigh approximately 5 grams of sample into 250 mL erlenmeyer flask.
2. Add approximately 250 mL of acetone and a stir bar and stopper securely.
3. Stir vigorously on a magnetic stirrer for at least 1 hour or until NC dissolution is complete.
3. Vacuum filter slowly through a Buchner funnel with filter paper covered with a celite cake.
4. Rinse adequately with acetone to transfer dissolved nitrocellulose into the filtrate.
5. Transfer filtrate quantitatively to a pre-weighed 250 mL beaker.
6. Air dry in hood until completely dry.
8. Weigh beaker and residue.
9. Calculate % nitrocellulose as follows.

$$\%Nitrocellulose=\frac{100\times(weight\ of\ beaker\ with\ residue-weight\ of\ beaker)}{sample\ weight}$$

Nitrocellulose contents of all samples except 1 through 4 were determined using the following procedure:

1. Weigh approximately 10 grams of sample into 250 or 500 mL erlenmeyer flask.
2. Add approximately 250 mL of acetone and a stir bar and stopper securely.
3. Stir vigorously on a magnetic stirrer for at least 1 hour or until NC dissolution is complete.

4. Remove the stir bar rinsing thoroughly with acetone.
5. Re–stopper and allow to settle at least 16 hours (over night).
6. Decant extract into a perforated ceramic Buchner funnel without filter paper and vacuum filter.
7. Rinse compost sediment in flask with two approximately 75 mL portions of acetone transferring completely into the Buchner funnel.
8. Assure quantitative washing of NC into the filtrate.
9. Transfer filtrate to 500 mL volumetric flask.
10. Bring to volume with acetone and shake thoroughly.
11. Settle for at least 16 hours (over night).
12. Withdraw a 15 mL aliquot using a volumetric pipette. Assure that settled and floating solids are excluded from this aliquot.
13. Pipette this aliquot into a pre–weighed aluminum weighing pan.
14. Repeat 12. and 13. making a second pan.
15. Air dry in hood, placing on a ceramic ring stand base warmed in an 100°C oven (prevents excessive moisture condensation).
16. When all trace of acetone odor is gone dry in 60° C oven for 30 minutes.
17. Cool in desiccator for at least 10 minutes.
18. Reweigh pan with residue.
19. Calculate the % nitrocellulose as follows.

$$\%Nitrocellulose = \frac{50000 \times (weight\ of\ pan\ with\ residue\ -\ weight\ of\ pan)}{15 \times sample\ weight}$$

Appendix D
Critical Diameter Test Description and Application

Critical Diameter (C_d) Test

The NC/amendment mixture (acceptor material) is subjected to pressures of a detonating high–energy donor to determine the minimum dimension required to induce a sustaining explosive reaction in the acceptor material. Testing is conducted using various diameters of NC/amendment samples and confinement as shown in Figure 1.

The acceptor test sample length is maintained at a minimum of four times its diameter. Twenty four inch sample lengths were used for all tests during this study. The explosive donor (Composition C–4) diameter is equal to three times its diameter plus one inch for the initiating cap. The explosive donor is initiated by a M6 blasting cap. Propagation of the explosive reaction is determined by examination of the container damage. A positive reaction (propagation) is indicated when the pipe is split the full 24 inch length, otherwise a failure reaction is reported. The reaction velocity is often measured using a resistance wire probe inserted inside and along the length of the container (Figures 1 & 2). The reaction velocity profile is used to determine increasing, steady state, or decaying reaction.

Critical diameter data are reported as the largest sample dimension which showed no evidence of propagating an explosive reaction through the test specimen. Test information is used to assess explosive propagation potentials of test sample and explosive configurations encountered during process situations.

Resistance Wire Probe

The resistance wire probe shown in Figure 2 is used to measure the test sample reaction velocity during critical height to explosion or critical diameter testing. The probe is connected to an oscilloscope so that voltage changes in the tube/resistance wire circuit are monitored. The pressure front accompanying an explosive reaction collapses the aluminum tube onto the resistance wire, producing a change in the circuit resistance and a corresponding change in the magnitude of the input voltage signal to the oscilloscope. The voltage signal, interpreted as container height and expressed as a function of time, provides a velocity profile of the reaction through the entire sample length.

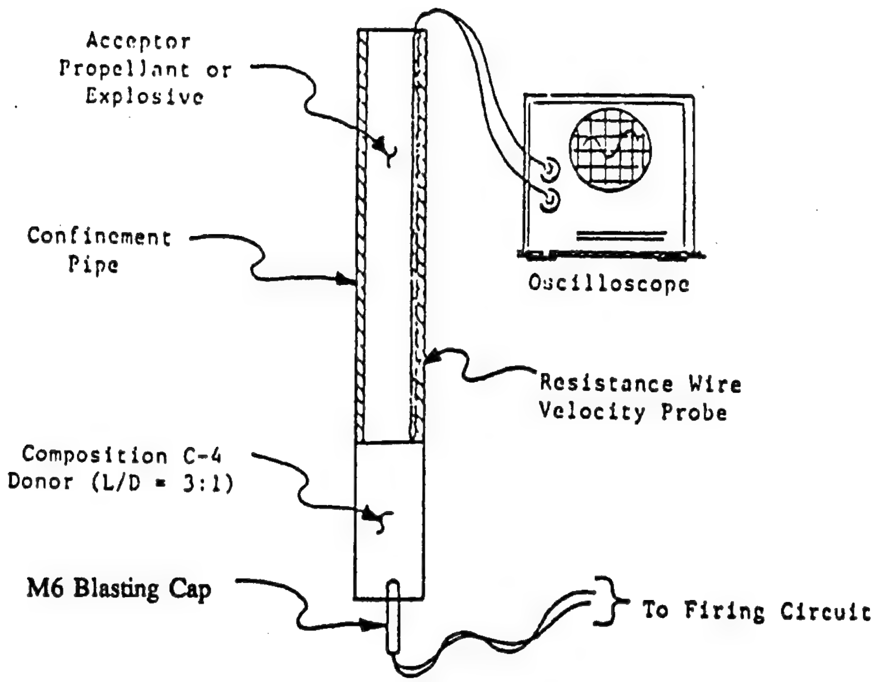


Figure 1 Critical Diameter Test Setup

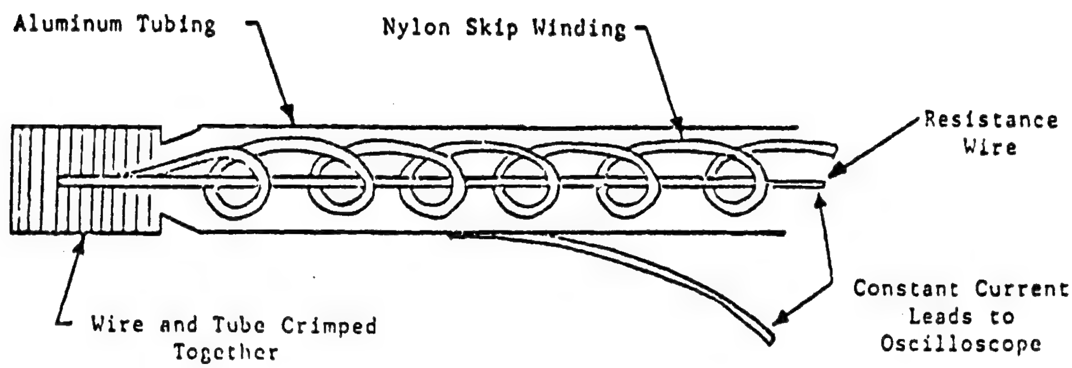


Figure 2 Resistance Wire Probe Test Setup

Appendix E
Deflagration to Detonation Test Description and Application

Deflagration to Detonation Test (DDT)

The experimental arrangement for the DDT Test is shown in Figure 1. The sample of the material to be tested is contained in an 18 inch length of 3 inch diameter schedule 80 carbon steel pipe with inside diameter of 2.9 inches and a wall thickness of 0.30 inch, capped at both ends with "3000 pound" forged steel pipe caps.

The sample is subjected to the thermal and pressure stimulus generated by an igniter consisting of a mixture of 50 percent RDX and 50 percent grade FFFG black powder located at the center of the sample vessel. The igniter assembly consists of a cylindrical container 0.81 inch in diameter and of variable length, which is made from 0.01 inch thick cellulose acetate held together by two layers of nylon–filament–reinforced cellulose acetate tape. The length of the igniter capsule is 0.125 inch for each gram of igniter material. The igniter capsule contains a small lop formed from a 1 inch length of nickel–chromium alloy resistance wire 0.012 inch in diameter with lead wires 0.026 inch in diameter; the overall wire diameter including insulation is 0.05 inch. These lead wires are fed through small holes in a brass disc approximately 0.4 inch in diameter and 0.03 inch thick, which is soldered to the end of a 9 inch length of 1/8 inch steel pipe having a diameter of 0.405 inch; this pipe supports the igniter capsule and serves as channel for the igniter wires. The igniter is fired by a current of 15 amperes obtained from a 20 volt transformer.

Criteria

The criterion currently used in the interpretation of this test is that for a positive result either the pipe or at least one of the end caps <u>be fragmented into at least distinct pieces</u>, i.e., results in which the pipe is merely split or laid open or in which the pipe or caps are distorted to the point at which the caps are blown off are considered to be negative results. Although it may be argued that a small number of fragments does not indicate the development of a detonation, it at least indicates a very rapidly rising pressure which in a larger sample could lead to development of detonation.

DDT testing using a 20 gram igniter provides a strong thermal stimulus. Substances that yield a negative result with a 20 gram igniter are interpreted to have no significant explosive properties.

Source: Adapted from J. Edmund May, Richard W. Watson, and Richard J. Mainiero, U.S. Bureau of Mines, Department of the Interior, Pittsburgh, PA 15236.

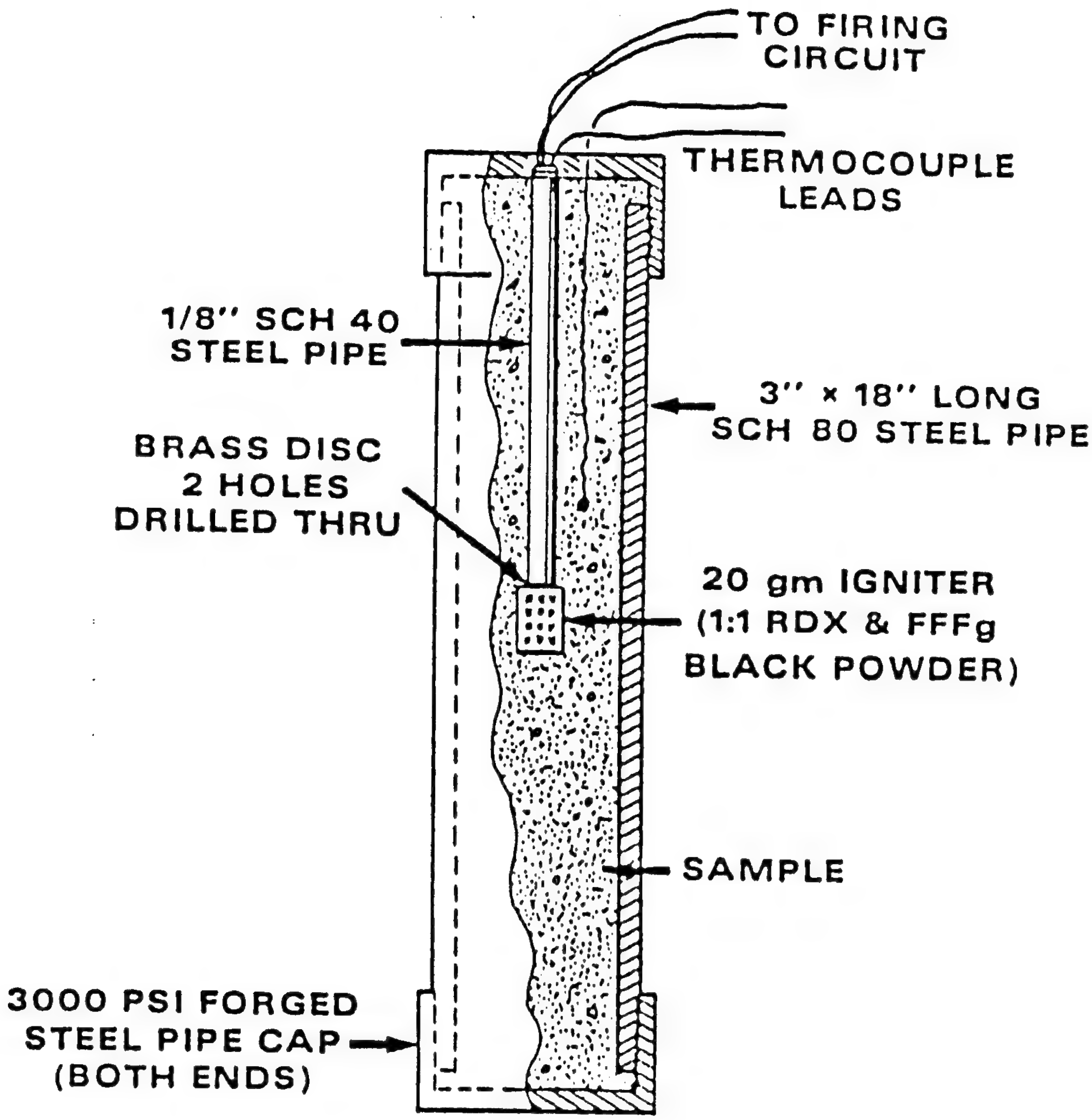


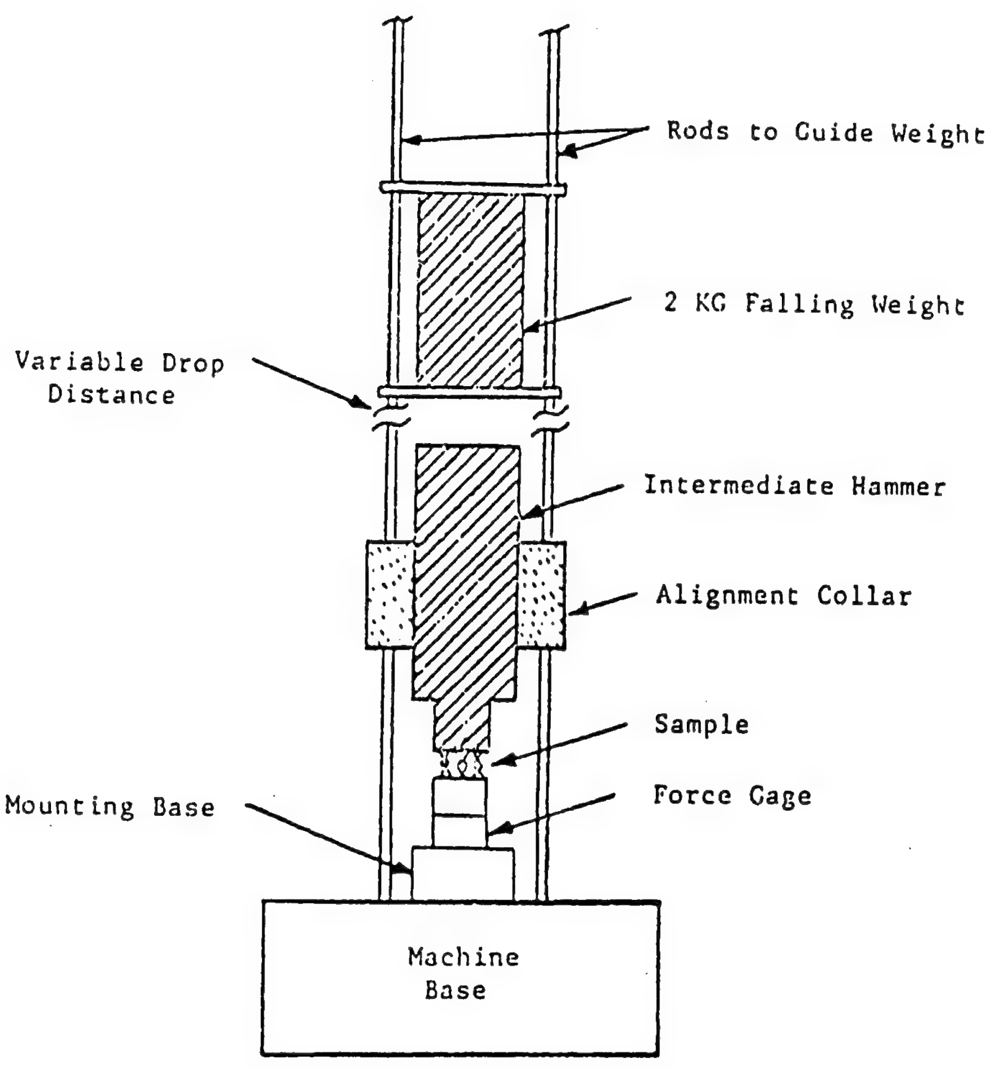
Figure 1 Deflagration to Detonation Test Setup

Source: Adapted from J. Edmund May, Richard W. Watson, and Richard J. Mainiero, U.S. Bureau of Mines, Department of the Interior, Pittsburgh, PA 15236.

Appendix F
Initiation Sensitivity Tests Descriptions

Impact Test

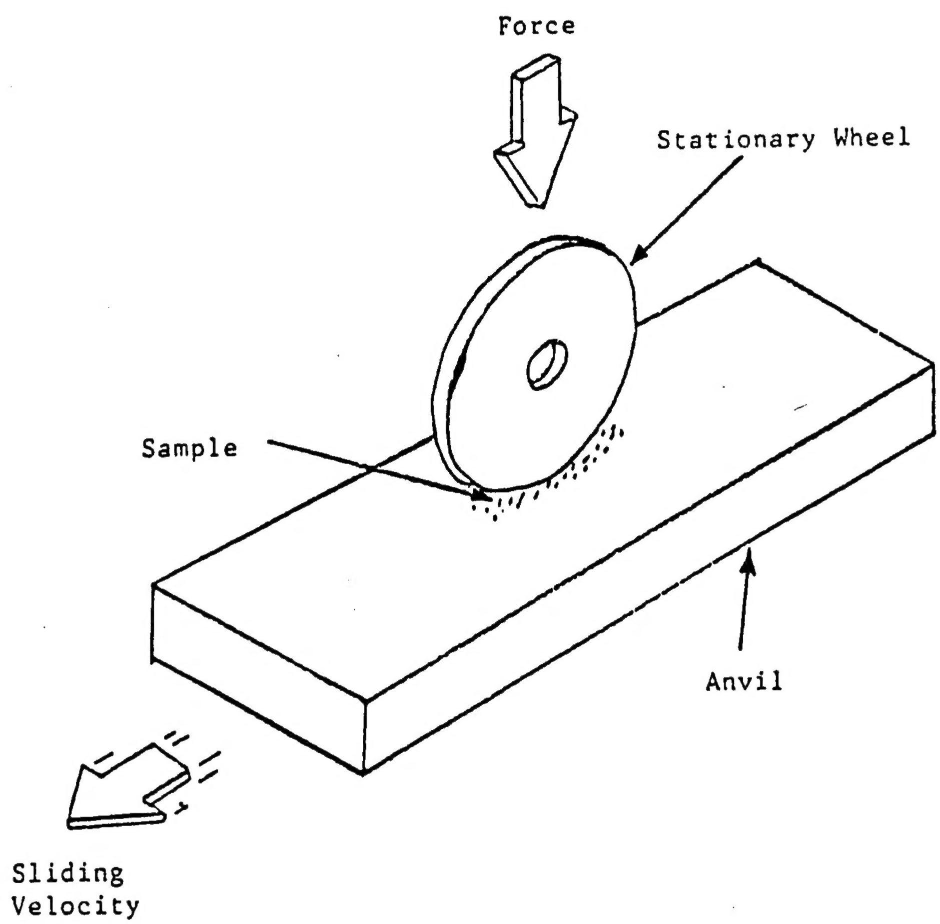
This test defines the maximum impact energy which will not ignite propellant or explosive materials. The material being tested is exposed to the impact energy of a falling weight as shown. The falling weight drop height and/or intermediate hammer materials of construction are varied to simulate impact conditions being assessed. The anvil and intermediate hammer materials of construction are steel unless otherwise noted. The impact energy is measured and expressed as ft–lbs per square inch of contact area between the impacting surfaces. Initiation of the sample under test is determined by the detection of gaseous combustion products using infrared absorption, an ionization chamber, or by the presence of odor, flash and/or noise.



Impact Sensitivity Test Setup

Friction Test

This test determines the maximum frictional energy which will not ignite propellant or explosive materials. The material being tested is exposed to the friction generated between a stationary wheel and a sliding anvil surface as shown. The pressure of the wheel upon the anvil, the speed of the anvil, and the wheel and anvil materials of fabrication are varied to simulate in process frictional forces being assessed. The wheel and anvil materials of construction are steel unless otherwise noted. The friction generated is expressed as pounds per square inch of contact area between the wheel and anvil at the anvil speed used for the test. Initiation of the sample under test is determined by the detection of gaseous combustion products using infrared absorption, an ionization chamber, or by the presence of odor, flash, and/or noise.



Friction Sensitivity Test Setup

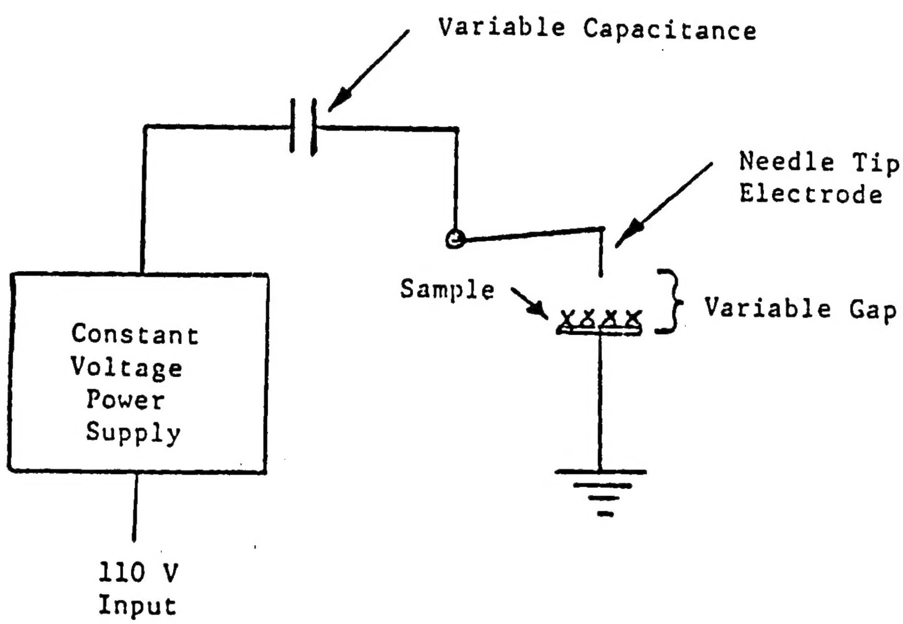
Electrostatic Discharge (ESD) Sensitivity Test

This test determines the minimum electrostatic discharge energy which will ignite propellant or explosive materials. Electrostatic energy stored in a charged capacitor is discharged through the sample being tested using the test setup shown. The energy discharged is measured in volts and recorded in joules according to the following relationship:

$$E = \frac{1}{2} C V^2$$

E = Energy, joules
C = Capacitance, farads
V = Potential, volts

Initiation of the sample under test is determined by the detection of gaseous combustion products using infrared absorption, or by the presence of odor, flash, and/or noise.



Electrostatic Discharge Sensitivity Test Setup

Glossary

Brisance	The ability of an explosive to shatter the medium which confines it; the shattering effect of the explosive. The brisance depends on the strength of detonation and velocity of propagation within the explosive. The strength of detonation depends on the volume of gases and amount of heat liberated. The velocity of detonation depends mainly on the chemical composition, but also upon density. It is raised by compression (i.e., increased density).
Bulk Densities	Also called gravimetric density. The ratio of the weight of a given volume of material to the weight of the same volume of water at a temperature of 70° F.
Compatibility	The property of two or more materials to co–exist in intimate contact without adverse reaction for an acceptable period of time.
Composition C–4	A secondary explosive used in the Critical Diameter test to induce an explosive shock into the material under test. See also Appendix D.
Compost Mixture	Compost amendments combined per specified percentages (recipes) to be mixed with Nitrocellulose.
Critical Diameter Test	See Appendix D.
Deflagration to Detonation Test	See Appendix E.
Fineness	A measure of how fine nitrocellulose has been cut during purification processing. Fineness is determined by a settling test, where measured quantities of cut NC and water are allowed to settle in a graduated cylinder for a specified time and the volume of the settled NC column is observed.

Nitrocellulose (NC)	An explosive derived from the reaction of cellulose with nitric acid. NC is generally manufactured from cotton linters (lint) or wood fibers (pulp). Radford Army Ammunition Plant manufactures NC to meet Military specification MIL–N–244A.
Nitrocellulose Fines	The small particles or separate fibers of NC found in the manufacturing process.
Sand Test	A measure of brisance where the amount of sand crushed in the test fixture is directly related to the explosive's ability to shatter the medium which confines it.
Stabilized NC	NC that has been treated by a combination of washing and cutting to remove residual nitrating acids from the nitrocellulose fiber.
Taliani Test	A test method used to determine chemical compatibility of materials. Equal parts of the materials are mixed and placed in a sealed container. Gas production is measured as evidence of reactivity and indicative of incompatibility.